IS 7689 (1989): Guide for the control of undesirable static electricity [ETD 20: Electrical Installation]

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(Reaffirmed 2005)

Indian Standard

GUIDE FOR CONTROL OF UNDESIRABLE STATIC ELECTRICITY

(First Revision)

भारतीय मानक

अवांछनीय स्थैतिक विद्युत नियंत्रण की मार्गदर्शिका

(प्रथम पुनरीक्षण)

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Electrical Installations Sectional Committee, ETDC 20

FOREWORD

This Indian Standard (First Revision), was adopted **by the** Bureau of Indian Standards on 29 May 1989, after the draft finalized by the Electrical Installations Sectional Committee had been approved by the Electrotechnical Division Council.

Static electricity occurs commonly in industry and in daily life and can be a source of danger as well as discomfort or inconvenience. The main hazard is that of explosions and fires initiated by electrostatic discharges, but shocks to personnel can also. on occasion, cause accidents. In addition, static electricity introduces operational problems during manufacturing or handling processes, for example, by causing articles to adhere to each other or attract dust.

Static electricity is generated in many operations, including the flow of liquids or powders, the production of sprays and the contact and separation of solids, and, therefore, gives rise to problems in a wide range of industries. The purpose of this guide is to provide recommendations for the control of static electricity. In some cases, static electricity is an integral part of a process, for example, paint spraying, but more often it is an unwelcome side effect and it is with the latter that this guide is concerned.

It is very seldom that an electrostatic hazard occurs in isolation. Precautions against static electricity should, therefore, be consistent with those 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 basis of safety covering all risks be considered. In particular, care should be exercised in the provision of earthing systems where they may interfere with other protective systems (for example, cathodic protection or intrinisically safe electrical equipment).**

Besides providing general guidelines. this guide details principal methods of safe control and dissipation of static electricity generated by solid objects, persons, liquids, dusts and gases which contain entrained solid or liquid particle (transfer of pure gas generates no static). It further includes recommendations for some **specific processes in which the generation of static charges is a major hazard or inconvenience. However, there are a multitude of processes in which static causes operating problems, and it is not possible to include** specific recommendations on back of them. **It is felt that together with the principal control methods, the guide is intended to promote an understanding of the problems thereby providing a sound basis on which judgement** can be applied for sowing problems not specifically mentioned.

Although **lightning is a form of static electricity of atmospheric origin -It is not intended that this guide should be used to** obtain guidance on the protection of structures against lightning. For this purpose, reference should be made to IS:2309-1980 'Code of practice* for protection of buildings and allied structures against lightning (*second revision*)'.

This guide is divided into five sections as follows:

Section 1 General and fundamentals of static electricity,
Section 2 Electrostatic hazards and their control,
Section 3 Earthing and bonding,
Section 4 Methods of measuring or estimating various parameters, and
Section 5 Recommendations for -particular industrial situations.

In the preparation of this standard, assistance has been derived from the following standards issued by the British Standards Institution:

BS 5958 Code of practice for control of undesirable static electricity:

Part 1 : 1980 General considerations
Part 2 : 1983 Recommendations for particular industrial situations

Composition of Electrical Installation Sectional Committee, ETDC 20, which was responsible for the preparation of this standard is given in Annex A.

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, shall be rounded off in accordance with IS : 2-1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

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Indian Standard

GUIDE FOR CONTROL OF UNDESIRABLE STATIC ELECTRICITY

(First Revision)

1 SCOPE

1.1 This standard covers guidelines on the control of undesirable static electricity.

1.2 This guide gives basic information on the generation of undesirable static electricity in solids, liquids and gases and also on persons, and describes how the charges produced give rise to discharges which may cause ignitions or electric shocks. It gives the methods available for minimizing such generation and for safety dissipating the charges produced.

1.3 Guidance is included in this standard on the means of measuring or estimating the parameters which need to be taken into account when deciding upon the action to be taken to control static electricity.

1.4 This standard also deals with static electricity problems which are encountered in particular situations during the handling of different types of materials including liquids, powders, gases, sprays, explosives and electro-explosive devices. In each case the source and nature of the hazard or nuisances are identified and specific recommendations are then given for dealing with them.

1.5 The static electricity problems that can occur with personnel and their clothing are also described and the precautions are given for avoiding these problems.

2 REFERENCES

2.1 The following Indian Standards are necessary adjuncts to this Code:

IS No.	*Title*
IS 2309 : 1989	Code of practice for protection of buildings and allied structures against lightning (*second revision*);
IS 3043 : 1987	Code of practice for earthing (*first revision*);
IS 5572 (Part 1) : 1978	Classification of hazardous areas (other than mines) for electrical installations : Part I Areas having flammable gases and vapours (*first revision*).

SECTION 1 GENERAL AND FUNDAMENTALS OF STATIC ELECTRICITY

3 DEFINITIONS

3.1 Antistatic Conductive (as an adjective)

Used to indicate that a material is, by virtue of its low resistivity, incapable of retaining a significant electrostatic charge when in contact with earth.

NOTE — The terms 'antistatic' and 'conductive' are frequently used as synonyms, hence the common definition above. However, in such contexts where they have specific meanings, -for example, in relation to footwear, the above definition is qualified in the appropriate clauses of this code.

3.2 Antistatic Additive

A substance added to a liquid or a solid in order to increase its conductivity so that it is incapable of retaining a significant electrostatic charge when in contact with earth.

3.3 Bonding

The use of an -additional independent connection between conductors to provide electrical continuity when this cannot otherwise be ensured.

3.4 **Breakdown Strength**

The minimum electric field strength in a medium at which electrostatic discharges can occur in a given situation.

3.5 Conductivity

The reciprocal of resistivity.

3.6 Conductor

A material possessing an electrical conductivity sufficiently high to render it incapable of retaining an electrostatic charge unless insulated from earth.

3.7 **Earthing**

The electrical connection of a conductor to the main body of the earth to ensure that it is at earth potential.

3.8 **Flammable**

Capable of being ignited.

3.9 **Flammable Material**

A gas, vapour, liquid, dust or solid that can react continuously with atmospheric oxygen and that may therefore sustain fire or explosion when such reaction is initiated by a suitable spark, flame or hot surface.

NOTES

1 Many liquids and solids, though regarded as flammable, nevertheless do not normally burn. The application of heat to such materials serves to release vapour that may burn with atmospheric oxygen. The heat of the subsequent reaction serves to release further vapour for combustion. Flame may propagate through suspensions of dusts by this mechanism.

2 In normal usage 'gas' and 'vapour' are synonymous.

3.10 Flammable Mixture, Explosive Mixture

A mixture with air of a flammable material? in the form of a gas, droplets or dust, which is within the flammable range and therefore capable of being ignited.

3.11 **Flammable Range**

The range of concentrations in air of a flammable material, in the form of a gas, droplets or dust, between the lower and upper flammable limits.

3.12 **Hazardous Area**

An area in which flammable or explosive gas-air mixtures are, or may be expected to be, present in quantities such as to require special precautions against'ignition.

Hazardous areas are classified into the following three zones [see IS 5572 (Part 1): 1978].

Zone 0	In which an explosive gas-air mixture is continuously present or present for long periods.
Zone 1	In which an explosive gas-air mixture is likely to occur in normal operation.
Zone 2	In which an explosive gas-air mixture is not likely to occur in normal operation, and if it occurs it will exist only for a short time.

3.13 Incendive

Capable of igniting a prescribed flammable mixture.

3.14 Inert Gas

A gas or a mixture of gases incapable of supporting the combustion of a flammble material.

3.15 Ion

An atomic or molecular particle carrying electrical charge.

3.16 Lower Flammable Limit

The concentration in air of a flammable material, in the form of a gas, droplets or dust, below which there is insufficiency of the material to support and propagate combustion.

3.17 Mass Charge Density

The net quantity of charge carried by unit mass of a material.

3.18 Minimum Ignition Energy

The smallest quantity of energy that can ignite a mixture of a specified flammable material with air or oxygen, measured by a standard procedure.

3.19 Non-conductor

A material possessing an electrical resistivity sufficiently high to enable it to retain enough charge to give rise to electrostatic effects.

3.28 Relaxation

The dissipation of an electrostatic charge by conduction.

3.21 Relaxation Chamber

A part of a liquid flow system which provides sufficient residence time for the charge on the liquid to be reduced to a safe level.

3.22 Relaxation Time

The time required for the charge or potentialon a liquid or a solid to decay to $1/e$ of its original level (e is the base of natural logarithms).

3.23 Surface Charge Density

The net quantity of charge per unit area of the surface of a solid or a liquid.

3.24 Surface Resistivity (of a substance)

The resistance between the opposite edges of a square.

3.25 Upper Flammable Limit

The concentration in air of a flammable material, in the form of a gas, droplets or dust, above which there is insufficient of the air to support and propagate combustion.

3.26 Volume Resistivity (of a substance)

The resistance at unit length and unit cross-sectional area.

4 STATUTORY PROVISIONS

4.1 The regulations or control of static laid by the statutory bodies like Directorate General of Civil Aviation, Chief Inspectorate of Factories, Department of Explosives, etc, shall be taken into account.

5 ELECTROSTATIC CHARGING

5.0 Introduction

The primary source of electrostatic charge is contact electrification, where two dissimilar materials are brought into contact and then separated, carrying equal and opposite charges. Conducting objects may also become charged by the process of induction from another charged object or objects in the vicinity. Objects can also receive charge by direct transfer either from-other objects or by the impingement upon them of a stream of ions.

5.1 Contact Electrification

Contact electrification 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 these may be charged by contact, so that such a gas can carry an electrostatic charge.

In the case of dissimilar solids, initially uncharged and at the same, normally 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 there is a potential difference between them which is of the order of 1 V. 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. This higher potential difference tends to drive charge back across the interface whilst any contact remains. 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 material, or both, is a non-conductor, the recombination cannot take place completely and the separating materials hold part, at least, of their charges. Because the clearance between the surfaces when in contact is extremely small the potential generated on separation can easily reach many kilovolts despite the small amount of charge involved. For reasons not fully understood the charging is enhanced if the contact and separation involves rubbing.

Contact electrification in liquids depends on the presence of ions or sub-microscopic charged particles (the latter are usually less important). Ion (or particles) of one polarity are adsorbed at the interface and they then attract ions of opposite polarity which form a diffuse layer of charge close to the surface. If the liquid is then moved relative to the interface, it carries away this diffuse layer, thereby bringing about separation of the opposing charges. As in the case of solids a high voltage is generated because of the work done to bring about the separation, provided that the liquid is sufficiently non-conducting to prevent recombination. Such processes can occur at both solid/liquid and liquid/liquid interfaces.

5.2 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 at the same time there is a separation of opposing charges in the conductor under the influence of the field. If it is insulated 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 is capable of an electrostatic discharge.

If, while it is in the field, the conductor is momentarily earthed, its potential is reduced to zero, but an imbalance of charges remains on it. Removal of the conductor from the vicinity of the original charged object, however, makes the remaining charge available to provide a spark. This type of induction sparking can be hazardous, for example, in the case of an insulated person moving about near electrostatically charged materials.

5.3 Charge Transfer

Whenever a charged object makes contact with one that is uncharged, the charge is shared between them to the extent that their conductivities allow. This is a potent source of electrostatic charging when charged sprays, mists or dusts impinge upon a solid object, for example, by settling. A similar transfer of charge can also take place when a stream of gaseous ions is incident upon an initially uncharged object.

6 RETENTION OF ELECTROSTATIC CHARGES

6.1 Even after separation in the charging process, electrostatic charges will quickly recombine either directly or via the earth unless they are prevented from doing so. If a charge is on a non-conductor it is retained by virtue of the resistance. of the material itself. To retain charge on a conductor it has to be insulated from other conductors and from earth by means of a non-conductor. It is shown in 15.2 that to retain a significant electrostatic charge a resistance to earth in excess of 1.MΩ is required.

Pure gases under normal conditions are non-conductors and the suspended particles, or droplets, in dust clouds, mists or sprays can therefore retain their charges, often for very 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. This process is known as relaxation. The resistance and resistivity or conductivity values which are needed to produce hazardous situations depend greatly upon the system under consideration and will be discussed in Section 2.

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

$$V = IR\,(1 - e^{-t/RC})$$

where

V is the potential of the conductor (in V)

C is its capacitance (in F)

R is the leakage resistance to earth (in Ω)

I is the electrostatic charging current (in A)

t is the time from' the commencement of charging (in s)

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

$$V_{max} = IR$$

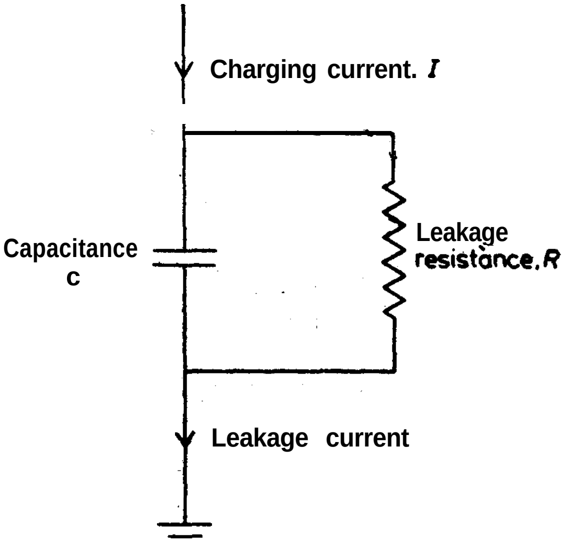


FIG. 1 EQUIVALENT ELECTRICAL CIRCUIT FOR AN ELECTROSTATICALLY CHARGED CONDUCTOR

7 ELECTROSTATIC DISCHARGES

7.0 Introduction

Charge retained on a liquid or a solid creates a hazard only if it is discharged to another body or, more usually, to earth. Electrostatic discharges vary greatly in the type and incendivity. In this Code they are classified as described in the following paragraphs, although the differentiation between the various types is not completely definite.

7.1 Sparks

A spark is a discharge between liquid or solid conductors. It is characterized by a well defined luminous discharge channel carrying a high density current. Ionization 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 a level known as the breakdown strength, which depends upon the gap width. For flat or large radius surfaces 10 mm or more apart this field strength is about 3×10^3 kV/m and it increases somewhat as the gap decreases.

Because the bodies concerned in the discharge are conductors, all the charge is drawn into the spark, which in most practical cases dissipates almost all the available energy. Referring to the equivalent electrical circuit of Fig. 1, therefore, the energy of the spark is:

$$E = \tfrac{1}{2} QV = \tfrac{1}{2} CV^2$$

where

E is the energy dissipated (in J)

Q is the quantity of charge on the conductor (in C)

V is its potential (in V)

C is its capacitance (in F)

This is the maximum value of energy; the energy in the spark is less if there is resistance in the discharge path to earth, and the duration of the spark is then also greater.

Typical values for the capacitances of conductors are given in Table 1.

A typical calculation of spark discharge energy is that involved when an unearthed metal drum is filled with powder from a grinding unit. In such a case I might be 10^{-7} A. The leakage resistance of the drum to earth, R, is, for example, $10^{12}\,\Omega$ and its capacitance about 50 pF. The maximum voltage on the drum is then:

$$V_{\text{max}} = IR = 100 \text{ kV}$$

and the maximum energy released in spark discharge would be

$$E_{\text{max}} = \tfrac{1}{2} CV^2_{\text{max}} = 250 \text{ mJ}$$

The charge retained on the drum to give a potential of 100 kV is

$$Q_{\text{max}} = CV_{\text{max}} = 5 \times 10^{-6} \text{C}$$

Table 1 Typical Electrical Capacitances

(*Clause* 7.1)

Object	Capacitance
	pF
Small metal items (scoop, hose nozzle)	10 to 20
Small containers (bucket, 50-litre drum)	10 to 100
Medium containers (250 litres to 500 litres)	50 to 300
Major plant items (reaction vessels) immediately surrounded by earthed structure	100 to 1000
Human body	100 to 300

7.2 Corona

This is a form of discharge from a conductor when it is very small, pointed, or has a sharp edge, that is, where a surface with a small radius of curvature exists. The discharge may be directed towards another object, or it may be dissipated into the atmosphere.

The field strength near the pointed feature is very large and falls off rapidly with increasing distance from it. The gas adjacent to the point is ionized and current can, therefore, leave the conductor. However, farther away from the point ionization is not complete and a low stable current is set up which is controlled by the gas conduction in this area. It is known as a corona discharge and is characterized by a hissing sound and, sometimes, by a faint glow.

A corona discharge may continue indefinitely or it may be in discrete short bursts. The energy density in the discharge is much less than in a spark. In certain circumstances, for example, if there is an increase in the potential of the pointed conductor, corona can develop into a spark to another object.

7.3 Brush Discharges

Brush discharge occurs from a charged non-conductor to a conductor. It **takes the form of spark-like discharges from discrete areas of the surface of** the **non-conductor; effectively, each discharge** is a small spark limited by the quantity of charge that can flow to it over the surface. The total discharge often has a brush-like appearance. If the conductor to which the current is flowing is pointed, the discharge at the conductor will be in the form of corona.

The localized energy density in a brush discharge may be high enough to be incendive; empirical tests suggest, however, that the energy release is unlikely to exceed about 4 mJ.

7.4 Propagating Brush Discharges

This type of discharge is a development of the normal brush discharge which can occur from a high resistivity non-conductor in sheet form with large opposing charges on its two surfaces. Often the sheet is backed by a conductor, but the essential point is that the sheet is polarized and in the same state as the dielectric of a charged capacitor. If a conductor approaches the non-conductor surface the resultant electrostatic field promotes ionization across a large area of the surface. A discharge can then take place in which the charge from an extensive area of the non-conductor rapidly flows to the initial discharge point through the ionized gas adjacent to the surface. The result is an intense and highly energetic spark-like discharge which can be very dangerous.

7.5 Field Emission Discharges

The energy of this type of discharge is very small and it is likely to be of concern only when explosives are involved. The discharges described so far have all depended upon gas ionization brought about by high field strength, but it is believed that a different ionization process operates in field emission discharges, that is, possibly the ejection of electrons from the surfaces; surface condition appears to be important. Discharges have been observed with a potential difference of 50 V if two conductor surfaces are brought within a distance of 10^{-3} mm of each other, which is equivalent to a field strength of about 5×10^4 kV/m. These figures compare with afield strength of about 3 × 10s kV/m for the more usual discharges, with a threshold potential difference of about 300 V.

8 INCENDIVITY OF ELECTRICAL DISCHARGES

NOTE - The data given in this clause are, strictly speaking, only appropriate to normal atmospheric temperatures. If higher temperatures are involved, specialist advice should be sought.

8.1 Flammability and Explosivity

8.1.1 *Flammable Mixtures*

In the combustion process flammable material reacts with an oxidant to liberate energy, The oxidant is usually air but it can be another gas mixture, containing more or less oxygen than air, or some other oxidizing agept.

A mixture in air of a flammable material in the form of a gas, droplets or dust cannot burn unless its composition lies within two limits, known as the lower and upper flammable limits anp normally expressed in terms of the concentration of flammable material in air. The range of concentrations between these limits is known as the flammable range, and any mixture within this range is termed a flammable mixture. The majority of gases have flammable limits within the range 2 (*v/v*) to 10 percent (*v/v*). However, there are substances, for example, acetylene, ethylene and hydrogen, whose flammable limits exceed this range.

In general, it is possible to avoid an explosion hazard due to an electrostatic discharge, or any other source of ignition, by eliminating any flammable mixture, that is, present. This can be done either by ventilation with air to reduce the concentration of the flammable material below the lower flammable limit or by adding inert gas. An inert gas is one containing little or no oxygen, such as boiler flue gas, and by its use the oxygen content of the atmosphere can be reduced to such a low figure that combustion is not possible at any concentration of flammable material in air. The required oxygen concentrations are, for example, about 11 percent *v/v* for hydrocarbon gases and about 5 percent *v/v* for hydrogen, compared with the normal atmospheric oxygen content of 21 percent *v/v*. It is usual in practice to include a factor of safety; a maximum oxygen content of 8 percent (*v/v*) is frequently specified for hydrocarbons.

8.1.2 *Explosives*

These are mixtures or compounds whose violent exothermic reaction can be initiated by electrostatic discharges or other sources of ignition without the intervention of air.

8.2 Ignition Energy

Whether or not an electrostatic discharge will ignite a flammable mixture depends upon the composition and temperature of the mixture the energy of the discharge and the distribution of this energy ,is space and time. In practical situations the most frequent source of ignition is a spark from an insulated conductor, and a spark is therefore the commonly accepted means of measuring ignition energies, using a voltage of at least IO kV. For a given flammable material a graph of the lowest energy for ignition as a function of concentration in air takes the form shown in Fig 2. The energy corresponding to the lowest point on this curve is called the minimum ignition energy and is the best general measure of the smallest quantity of energy needed to initiate an explosion or fire involving the flammable material in question.

Most organic vapours and hydrocarbon gases in air have minimum ignition energies in the range 0·01 m J to 1 m J. Carbon disulphide and hydrogen in air have values in the region of 0·02 mJ, while explosives can have minimum ignition energies as low as 0·001 mJ.

Similar considerations apply to dust clouds or liquid droplet suspensions except that the minimum ignition energies are higher than those of gases because of the need to heat up the suspended matter present. For dust clouds the values range from less than 2 mJ to greater than 5 000 mJ.

The minimum ignition energy of a dust cloud depends on the particle size distribution in the cloud, as well as on its chemical composition, although published data frequently do not specify the particle size. A decrease in particle size or an increase in the percentage of fines in general decreases the minimum ignition energy. In some cases this effect is very marked, as in the example given in Table 2.

Table 2 Example of Dependence of Minimum Ignition Energy on Particle Size of a Dust

(Clause 7.2)

Particle Size Range	Minimum Ignition Energy
μm	mJ
710 to 1680	> 5 000
355 to 709	250 to 500
180 to 354	50 to 250
105 to 179	< 10
53 to 104	c 10
5	< 10

As a practical guide, experience suggests that the sensitivity of a dust cloud to ignition is realistically determined by using dust that has passed through a 200 mesh (75 μm) sieve.

8.3 Assessment of the Incendivity of Discharges

Sparks from insulated conductors constitute the most important electrostatic ignition risk. As discussed in 7.1, sparks are of very short duration and, in many cases, virtually all the available electrostatic energy appears in the discharge. To assess the incendivity of such a discharge, therefore, it is usually valid to compare the stored energy, measured by $1/2 CV^2$, with the minimum ignition energy of the combustible material in question. The comparison may not be valid if there is resistance in the discharge path, because part of the stored energy may be dissipated in the resistance and the duration of the spark may increase.

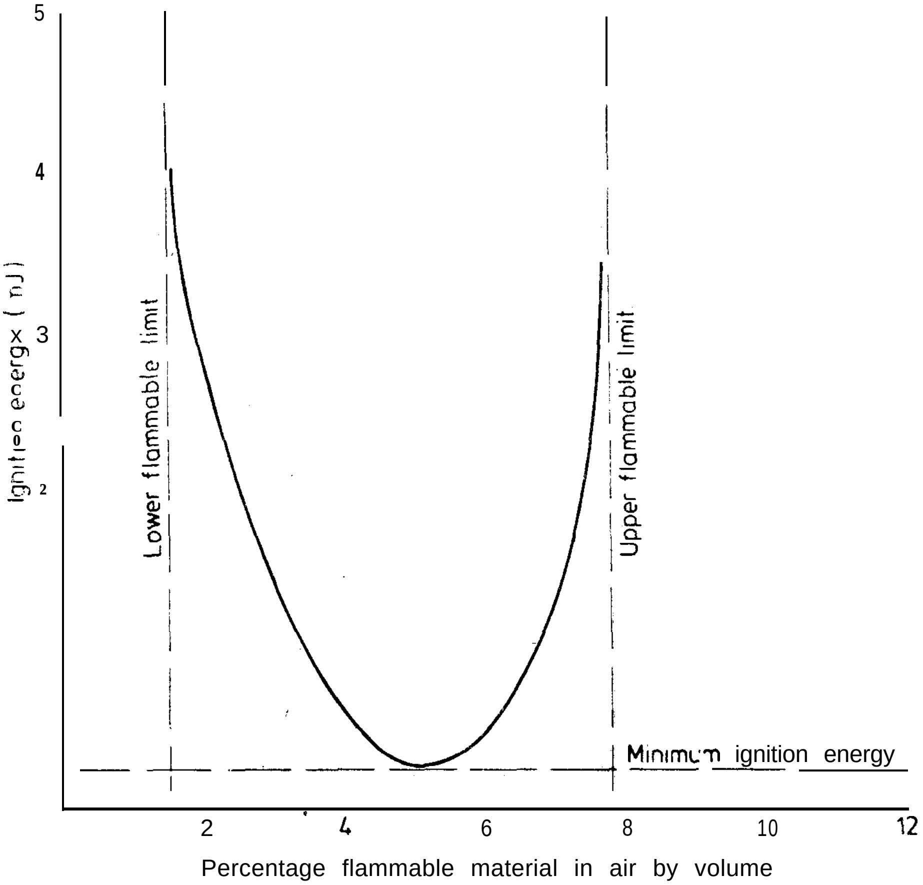
The incendivities of corona discharges are less than those -of sparks. The stored energy on a conductor, $L/2\ CV^2$, therefore, tends to over-estimate the ignition risk. The relatively low incendivity of corona allows it to be used in passive eliminators as a means of safely removing static electricity, although, if there is any possibility of the presence of a flammable mixture, it is essential that great care be taken in the design of the system.

There is no generally accepted method of determining the incendivity of the brush discharges from non-conductors. Usually the rate of release of energy is comparatively low because the high surface resistivity impedes the flow of charge but, due to the presence of high energy density cores, brush discharges can be more incendive than corona. A propagating brush discharge from a high resistivity non-conducting sheet, with or without a metal backing, is highly incendive. Where a precise assessment of the incendivity of a brush discharge is required, ignition tests should be made using the flammable mixture of interest. In the case of a propagating brush discharge, if the total energy stored on the non-conductor can be estimated, it may be compared with the minimum ignition energy.

9 PHYSIOLOGICAL EFFECTS OF ELECTROSTATIC DISCHARGES

9.1 The smallest spark energy that a person can feel when a discharge occurs to or from his body is about 1 mJ, that is, potential of about 2·5 kV if his capacitance is 300 pF. As the potential is increased, variations in response are observed. Some people find 10 mJ uncomfortable due to muscular contraction, whereas others can accept several hundred millijoules before they experience sharp muscular contraction. 1 000 mJ, (that is 1 J), affects everybody severaly. In incidents in which people have been rendered unconscious the energy of the discharge was estimated to be several joules.

Since in most situations discharge energies are below 100 mJ serious physiological shock is very rare. There are exceptions; for example, a discharge to a person due to highly charged particulate matter collected in a non-conducting container can be as much as several joules (see 12.2.3). Irrespective of whether the shock itself is harmful, the involuntary muscular reaction to a discharge may cause an accident through, for example, the dropping of a tool or by precipitating a fall.



NOTE — This graph is purely diagrammatic and is not to be used in any assessment of incendivity.

FIG. 2 IGNITION ENERGY AS A FUNCTION OF FLAMMABLE MATERIAL CONCENTRATION IN AIR

-SECTION 2 ELECTROSTATIC HAZARDS AND THEIR CONTROL

10 ELECTROSTATICS IN LIQUIDS

10.1 Charge Generating Mechanisms

10.1.1 *Flow of Single Phase Liquids Through Pipes*

When a liquid flows through a pipe, charge separation occurs (see **5.1**) and the liquid emerging from the pipe is charged. The amount of charge is dependent, amongst other things, upon the flow conditions. Turbulent flow generates more charge than laminar flow; for a single phase liquid the current generated is roughly proportional to the velocity in the case of laminar flow and to the square of the velocity in the case of turbulent flow. Because laminar flow problems are less severe this code will deal exclusively with turbulent flow conditions.

For single phase flow, the current generated by a liquid flowing through an infinitely long pipe, made of metal or of any material with a volume resistivity less than about $10^{12} \Omega$.m, does not change greatly with the conductivity and relative permittivity of the liquid. In practice, as the liquid levels the pipe it is no longer subject to the charge separation process and charge relaxes back to the wall of the pipe through the emerging liquid. Therefore, the net current carried by the liquid as it enters the receiving vessel decreases as the liquid conductivity increases.

Also, as the flow rate decreases the current decreases.

For single phase liquids whose conductivities are low enough for them to retain a dangerous charge, there are a number of empirical relationships giving the maximum charge generation. One such relationship leads to the following approximate expression for the charge density on the liquid leaving an infinitely long pipeline:

$$\eta \approx 5v$$

where η is the charge density (in $\mu C/m^3$) and v is the liner velocity of the liquid (in m/s). Thus, for linear velocities of 1 m/s and 10 m/s the charge densities are about 5 $\mu C/m^3$ and 50 $\mu C/m^3$, respectively.

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

$$L > 3 v \tau$$

$$\text{and } \tau = \frac{\varepsilon \epsilon_0}{\gamma} \times 10^{12}$$

where

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

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

ε is the relative permittivity of the liquid,

ε_0 is the permittivity of free space ($8{\cdot}85 \times 10^{-12}$ F/m), and

γ is the conductivity of the liquid (in pS/m).

Very few data are available for charge generation during liquid flow in pipes made of materials having volume resistivities greater than $10^{12} \Omega$ m. It has been found that for liquids with conductivities in the range 1 pS/m to 100 pS/m the current leaving a polyethylene pipe decreases with increasing duration of the flow and finally reaches an equilibrium value in good agreement with that from a metal pipe. On this evidence, the expression for charge generation by a conducting pipe can be used to estimate' the equilibrium generation by a non-conducting pipe. However, prior to the establishment of equilibrium, the current is greater than that for a conducting pipe, but this is unlikely to affect the degree of hazard in a sustained pumping operation.

10.1.2 *Flow of Liquid/Liquid or -Liquid/Solid Mixtures Through Pipes*

Whenever such mixtures are pumped through pipes, charge generation occurs in the same way as with a single phase liquid. The rate of generation may be greater than with a single phase because of the increased interfacial area, but it is not amenable to calculation.

10.1.3 *Flow of Liquids Through Strainers and Filters*

Strainers and gauzes are very coarse filters, usually with mesh numbers less than 350 (30 μm apertures) designed to remove large particles from liquids. They do not normally cause any significant current generation and can be ignored when handling single phase liquids. If a second phase is present they may aid its dispersion, thereby promoting increased charge generation elsewhere in the system.

Fine particle filters can be prolific generators of static electricity; in general, the more stringent the filtration requirement the greater the charge generation. The current generated by very fine micronic filters can exceed, by several orders of magnitude, produced by a pipeline. Typical charge densities in the liquid leaving such a filter can be in the range 10 $\mu C/m^3$ to 5 000 $\mu C/m^3$. Unfortunately it is not possible to predict the charge generation of a fine particle filter; even apparently identical filters of the same type can give widely differing results.

Current generation in a fine particle filter depends upon flow rate, liquid conductivity, the type of ions in the liquid and, possibly, the state of the filter element surfaces. In general, generation increases with increasing flow rate. As the liquid conductivity increases from a very low level (0·1 pS/m), generation at first also increases. This is because the increasing ion concentration makes a positive contribution to both conductivity and charge generation. However, the current emerging from the filter reaches a maximum and then declines with further increase in conductivity as the normal relaxation process carries charge back to the filter. The lack of predictability of the current generation is attributed to variations in the nature and concentration of the ions present and to the ‘complexities of the liquid/filter element interface.

10.1.4 *Settling of Solids or Liquids in Liquids*

Any settling process, such as that of water in hydrocarbon, generates charge. The process of charge generation in such systems is very complicated and has been studied only to a very limited extent. Low conductivity of the continous liquid phase promote the occurrence of a high settling potential by retarding relaxation.

10.1.5 *Splashing of Liquid Jets*

As liquid emerges from a pipe into a receiving vessel two processes may give rise to charged mist or spray.

In the first, the liquid is charged during its flow through the pipe as described in 10.1.1 and, if the liquid column is unbroken, part of the charge relaxes back to the pipe. If, however, the column breaks up into droplets, any remaining charge is distributed amongst the droplets. The resultant spray is therefore charged.

Secondly, if the jet hits an obstruction, additional charge can be produced by electrification at the point of impact and the resultant spray may, therefore, be highly charged. The magnitude of this charge is not predictable; it depends upon the nature and cleanness of the surface as well as on the type and concentration of ions in the liquid. In general, the more conducting the liquid, the greater the charge generation. For example, a water jet produces more charge than an oil jet, but water/oil mixtures may produce more than either water or oil.

10.1.6 *Ejection of Liquid Droplets from a Nozzle*

A wet gas stream issuing from a nozzle can be highly charged. The liquid layer on the inside of the pipe is sheared by the gas stream and broken up into droplets. If the sheared layer has a charge as a result of its motion along the pipe surface, the droplets emerging from the nozzle are charged. The amount of charge depends amongst other things, on the conductivity of the liquid and on the gas velocity.

10.1.7 *Stirring and Mixing*

Any motion of a liquid in a container generates static electricity, to an extent dependent upon the conductivity of the liquid and the relative motion between the liquid and the solid surfaces with which it is in contact. Normally, the amount of charge generated in much less than that produced by the flow of a liquid through a pipe or a fine filter, because the turbulence is less, but a hazard can arise in some blending operations.

10.2 Discharges Involving Liquids

10.2.1 *General*

For some processes it is possible to calculate both charge generation and charge retention (see 7.1) and hence to assess the degree of hazard due to a discharge and to decide upon counter measures. In many other cases, however, calculations are impossible and measurements have to be relied upon. This usually involves the use of electrostatic voltmeters or electrostatic field meters to monitor the problem and to determine the critical parameters. Because charge generation is very variable it is important to be satisfied that the worst case has been tested.

10.2.2 *Discharges from Liquids*

Charges that have been separated as a result of the flow of a liquid attempt to recombine. If’ the liquid has a low conductivity it can, however, retain the charge, irrespective of whether it is pumped into an earthed, conducting (normally metal) tank or into a non-conducting tank or container.

A measure of the rate of charge dissipation from a liquid in contact with earthed metal is its relaxation time, the expression for which was given in **10.1.1.** It is the time required for the potential of the liquid to fall to about 37 percent of its original level as it decays exponentially. It is accepted in any applications that if a liquid has a conductivity greater than 50 pS/m, equivalent to a relaxation time of about 0·35 seconds, it is incapable of retaining a hazardous charge. Alcohols and ketones are in this category and so also are all black petroleum oils (containing residual material) and crude oils. Clean or white oils. such as kerosene or gasolene, however, normally have conductivities below 50 pS/m, and are, therefore, able to retain a significant charge.

When a liquid is charged, electric fields exist both within the liquid and in the space around it. If these fields are high enough, discharges can occur. Discharges within the liquid are, in general, not an ignition hazard, but they may bring about chemical changes altering the specified properties of the liquid or causing corrosion of the plant involved.

Discharges in the atmosphere can be hazardous. Within a tank, the field strength between the liquid surface and earthed walls or structure can exceed the breakdown strength. It is rarely possible to estimate the energy of the resultant discharges and, in any event, this energy cannot be compared with the minimum ignition energy determined using metal electrodes.

It is sometimes possible to avoid a hazardous situation by controlling the rate of charge input to the tank so as to keep the field strength at the liquid surface below the breakdown value. This field strength can, in principle, be calculated from the input current given information on the conductivity of the liquid, the size and shape of the tank and of any internal structure, and the ullage of the liquid.

Charge retention on liquids in similar in both conducting and non-conducting containers although in the latter case relaxation may be controlled by the resistivity of the container. A non-conducting container can be expected to increase the possibility of discharges from a liquid, but few quantitative data are available on this subject.

10.2.3 ***Discharges from Solids***

Both non-conductors and conductors with a resistance path to earth greater than $10^6 \Omega$ can become charged through the agency of a liquid by many processes. These include:

a) flow of a low conductivity liquid past them (the charge may be due to contact electrification between the liquid and the object, of to charge transfer from a liquid already carrying charge_; examples are an insulated metal flange, an insulated section of metal pipe in a non-conducting pipeline or a length of non-conducting pipeline itself);

b) collection of charged liquid, as when charged liquid is poured into an unearthed can;

c) inmersion of a conducting object in charged liquid (the object takes up the potential of the point where it is situated in the liquid; an example is an unearthed metal component in a sampling or ullaging system), and

d) settling of charged mist or spray on the object, for example, an unearthed object in the vicinity of a steam leak.

The possibility of charging by induction should always be borne in mind where there are insulated conductors in the vicinity of charged liquid.

As described in 7, the discharges from conductors are usually sparks and are potentially hazardous. The energy can be calculated using the procedure given in 7.1. In some cases, for example,, an empty can floating in a liquid, the conductor may be mobile, and the calculation is then complicated because the capacitance is variable.

Discharges from non-conductors are considered in 12.

10.2.4 ***Charge Retention on Mists and Sprays***

Suspensions of charged droplets retain their charge by virtue of the insulation provided by the surrounding atmosphere. When the mist or spray is being produced continuously, as, for example, when washing a tank with water or injecting steam, the charge density builds up to an equilibrium value where the rate of input of charge is equal to the rate of loss by processes such as settling or impingement of the droplets on the structure of the tank.

There is an electric field both within and around a charged cloud of mist or spray. The field strength at any point depends on the charge density, the size and shape of the-cloud and the size and shape of the vessel; if any, containing the cloud. Insulated conductors within or near the cloud can be charged by induction or by the settling of droplets and are then capable of yielding incendive sparks to earth. With very high charge densities complete ionization could occur in the atmosphere between the droplets, leading to a lighting type discharge, but there is no evidence that this occurs in industrial situations. Corona discharges are possible, more especially from earthed projections to the cloud, and these are believed to contribute to the establishment of an equilibrium charge density in the cloud.

An important example of a charged mist is that produced during the water washing of the cargo tanks of tankers. One type of insulated conductor in this process is provided by isolated slugs of water produced as the water jets entering the tank break up.

10.3 Precautions Against Static Electricity from Low Conductivity Liquids

10.3.1 *General*

Measures to avoid ignitions due to static electricity (and any other sources of ignition) are necessary if the presence of a flammable mixture is known or suspected. One type of precaution is to eliminate the flammable mixture by ventilation with air or by inserting inert gas (see 8.1.1). Alternatively, the space in which the flammable mixture could form can be removed, for example, by means of floating roof tanks as used in the oil industry. In the absence of the possibility of a flammable mixture there may still be a risk of serious physiological shock; this can be eliminated by bonding and earthing both conductors and personnel.

If the presence of a flammable mixture is possible, electrostatic discharges should be controlled. The methods available are:

a) bonding and earthing of conductors, including personnel,

b) minimizing electrostatic charge generation, and

c) maximizing charge dissipation.

In some cases, these measures either singly or in combination may not be entirely adequate and they should then be supplemented by appropriate operational procedures and design features to avoid discharges.

Bonding and earthing are considered in detail in Section 4. Other methods are dealt with in 10.3.2 and 10.3.3. Because of the very wide range of possibilities, precise and totally comprehensive advice is difficult to give. Each application should be considered on its merits.

10.3.2 *Control of Charge Gerieration*

10.3.2.1 *Flow rate*

The generation of electrostatic charge increases with the rate of flow of liquids. Also, high velocities encourage the entrainment and dispersion of a second phase, such as water, thereby increasing charging in pipeline systems as well as allowing subsequent charge generation by settling in tanks. The point of entry into a tank should be at a low level and the flow velocity should be kept low until the incoming stream no longer breaks through the liquid surface.

A flow velocity of 1 m/s is recommended in the filling of storage tanks with low conductivity liquids (conductivities less than about 50 pS/m) when any second phase may exist in the pipe. A second phase is most likely to be present in the initial stages of a filling operation. It is not possible at present to make a general statement on the upper limit of velocity of flow rate to cover all tank filling operations when no second phase is. present. In the light of present knowledge it is undesirable in any case for the pipeline velocity to exceed 7 m/s, but in some instances it might need to be as low as 2 m/s.

10.3.2.2 *Free fall*

The splashing and impingement on surfaces, associated with the free fall of low conductivity liquids are sources of electrostatic charging. Free fall should be avoided in tanks, either by arranging for bottom entry of the liquid or by the use of a fill pipe extending to the bottom of the tank.

10.3.2.3 *Agitation and mixing*

Mechanical mixing or agitation of low conductivity liquids with air, steam, gas or jet nozzles. should be kept to a minimum because of the charge which may be produced on the mist or spray formed above the liquid.

10.3.2.4 *The presence of immiscible components*

The presence of a second liquid phase, commonly water, in a low conductivity liquid may increase electrostatic problems. As already indicated (*see* 10.3.2.1) the flow velocity should be kept at. about 1 m/s whilst the second phase is present. Efforts should be made to eliminate it, for example, by reducing the water bottom in tanks. as much as possible and by draining down thoroughly any water-flushed pipelines.

10.3.3 *Charge Dissipation*

10.3.3.1 Relaxation

When a liquid is highly charged, for example after passage through a fine particle filter, most of the charge can be dissipated by allowing the liquid to pass slowly through a relaxation chamber. This may be a small tank or, more frequently, a length of large-diameter pipe. For liquids: with conductivities down to 2 pS/m the residence time in the relaxation chamber should be 3 τ where τ is the relaxation time of the liquid, and for less conductive liquids it should be 100 seconds.

The charge on the liquid entering any metal container relaxes in a similar manner. Relaxation in non-conducting tanks is controlled by the relaxation time of the material of the tank. In such cases charge can be dissipated by arranging for the liquid to be in contact with earthed metal, usually an earthed metal plug at the bottom of the tank, or any earthed metal components, such as the fill pipe, extending to the bottom of the tank.

10.3.3.2 *Antistatic additives*

These additives increases the conductivity of liquids. The addition of such an additive to raise the conductivity to 50 pS/m or more decreases the relaxation time sufficiently to remove any electrostatic hazard in a conducting system.

10.3.3.3 *Ionization*

Radiation may be used to promote ionization of the atmosphere adjacent to the liquid surface to facilitate the leakage of charge from the liquid. This method can rarely be employed in practice because it usually requires a prohibitively large number of radio-active sources and it can only relax the charge on the liquid near the surface.

10.3.4 *Operational and Design Features*

Whenever there is the possibility of the presence of a flammable mixture, any metallic object lowered into a tank, for example, ullaging or sampling equipment, should be earthed and any person using such equipment should be earthed. However, if a low conductivity liquid is being pumped into the tank, a discharge may occur between the decending earthed equipment and the liquid surface as they approach each other. Dipping, ullaging or sampling should, therefore, be avoided whilst pumping is in progress and time should be left for relaxation on completion of pumping. For a single phase liquid in a metal tank a period of 3 τ or 100 seconds, depending on conductivity, is sufficient (see **10.3.3.1**). However, if the liquid contains a second immiscible phase, such as water in suspension, the delay should be 30 minutes to permit settling of the second phase and the relaxation of any settling potential.

A similar hazard exists if there are conductive earthed metal projections downwards into a tank which could discharge to the liquid surface as it rises towards them. Such projections should be avoided, unless it can be shown that charging is not at a dangerous level.

Earthing of conductors is the most commonly used precaution against static electricity and is usually comparatively simple to arrange. In a few instances, however, an unearthed conductor may inadvertently be present, for example, an empty can floating in a liquid. The greatest care should be taken to ensure the absence of such potential insulated conductors.

11 ELECTROSTATICS IN POWDERS

11.1 General

In this Code the term powder 'means particulate solid matter with particle sizes ranging from these in fine dust to granules or chips. The behaviour of powders has to be consideredboth when the particles are in suspension as a cloud and when they have settled as a bulked powder.

11.2 Charge Generation

Contact electrification occurs extensively in powders. The charging characteristics are often determined at least as much by surface contamination of the particles as by the chemical composition of the powder itself and charge generation is usually difficult to predict. Electrification can be expected whenever a powder comes into contact with a dissimilar surface, for example, inmixing, grinding, sieving, pouring, micronizing and pneumatic transfer.

The amount of charge carried by a powder in suspension in a gas cannot exceed a level at which the field strength at the surface of each particle is sufficient to produce ionization of the atmosphere around it, allowing charge to leak away. This field depends on the particle size and shape on a particle is about $10\mu C/m^2$. As the particles approach each other more closely the field strength at the boundary of the cloud increases, discharges occur and hence the total charge carried becomes less.

The charge carried by unit mass of powder is usually the critical parameter in considering electrostatic phenomena involving powders. In the case of spherical particles it is given by:

$$q = \frac{3\sigma}{dr}$$

where

q = mass charge density ($\mu C/\mu g$),

σ = surface charge density ($\mu C/m^2$),

d = density of the powder particles (kg/m^3), and

r = radius of particles (m).

A given powder in suspension in air retains its maximum mass charge density when it is well dispersed and approaches $10\mu C/m^2$. It is also evident from this relationship that a larger amount of charge can be carried when the particles size is small.

For the purposes of this Code it is helpful to divide powders into three groups depending on the volume resistivity of the material of which the particles are composed. These groups are:

a) low resistivity powders, for example, metals, having volume resistivities up to about $10^6 \Omega m$;

b) medium resistivity powders, for example, many organic powders, such as flour having volume resistivities in the approximate range $10^6 \Omega m$ to $10^{12} \Omega m$; and

c) high resistivity powders, for example, many synthetic polymers and some minerals, such as quartz, having volume resistivities above about $10^{12} \Omega m$.

In practice, low resistivity powders are rarely encountered. Even metal powders do not remain conductive for very long because oxide films on the particles increase their effective resistivity sufficiently to put them into the medium resistivity category. This Code is therefore predominantly concerned with medium and high resistivity powders. Problems can arise with low resistivity powders if they are insulated from earth, for example, in a non-conducting container.

Measurements with medium resistivity powders indicate that their mass charge densities depend on the process to which they have been subjected and on their degree of fineness, rather than on their chemical compositions. The charge density is for greater in grinding or micronizing operations than in sieving or pouring. One reason for this is that the former type of operation produce much smaller particles.

Table 3 gives measured data on the charge levels on medium resistivity powders emerging from different processes.

Table 3 Charge Generation on Medium Resistivity Powders

(Clause 11.2)

Operation	Mass Charge Density μC/kg
Sieving	10^{-3} to 10-5
Pouring	10^{-1} to 10-3
Scroll feed transfer	1 to 10^{-2}
Grinding	1 to 10^{-1}
Micronizing	10s to 10^{-1}

When a medium resistivity powders comes to rest in bulk the charge retained depends on the resistance between the powder and earth. If the powder is in an earthed container or in contact with earthed metal components, charge rotation is determined by the volume resistivity of the bulk powder, which includes the inter-particle resistances and is measured as described in section 4. The relaxation time of a bulked powder is given by the equation:

$$\tau = \epsilon \epsilon_0 \rho$$

where

τ is the relaxation time (in s)

ϵ is the relative permittivity of the powder,

ϵ_0 is the permittivity of free space ($8{\cdot}85 \times 10^{-12}$ F/m)

p is the volume resistivity of the powder (inΩm)

For a volume resistivity of $10^{12}\Omega$m this gives a relaxation time of about 20 seconds, so that, even making no allowance for contact resistance between the particles, medium resistivity powders at the upper end of the resistivity range can retain their charge for an appreciable period.

The charge generated on high resistivity powders depends much more on their mode of transfer, that is, whether in suspension or semi-bulked, than on the process to which they have been subjected. Not only are their volume resistivities very high, but they are also very hydrophobic and in bulk they are capable of retaining charge for hours or even days even when in contact with earthed metal. Charge retention is in many instances controlled by the field strength, and the surface charge density may therefore be of the order of $10 \mu C/m^2$.

11.3 Discharges Involving Powders

11.3.1 *Ignition Energy*

The processes of charge generation and retention in powders are in general not sufficiently well defined to permit calculations to be made of the energies likely to be involved in discharges, and tests using the system in question are the most reliable means of assessing the risks.

Where the spark energy can be calculated, such as. in discharges from insulated conductors in the vicinity of charged powders, it may be compared with the minimum ignition energy of the powder, measured by the method described in Section 4. There is another commonly used procedure for measuring minimum ignition energies of powders in which a capacitor is discharged through a transformer to a spark gap; the result is quoted in terms of the energy lost from the capacitor, making no allowance for losses in the transformer. The use of the result of this type of test in comparison with discharge energies understates the hazard and should be avoided.

11.3.2 *Discharges from Dust Clouds*

In principle, discharges can occur within dust clouds or from dust clouds to earth when the field strength due to the charged particles high enough. Recent work has indicated that the discharges are of a corona type. Spark or lightning type discharges have not been observed in dust clouds of the size encountered in industrial operations. On the basis of the evidence so far, the risk of an ignition due to a discharge from a dust cloud is very low, except for highly sensitive atmospheres, for example, very fine dust suspensions or flammable gas mixtures.

11.3.3 *Discharges from Bulk Powders*

The probability of an electrostatic discharge increases as the powder settles out in bulk form, thus concentrating the charge and increasing the field strength in the surrounding space.

In the case of medium resistivity powders most of the charge relaxes as the particles make contact with each other, provided that the powder is in an earthed metal container or in contact with earthed metal. In these circumstances it is unlikely that a discharge from the surface of the powder would be capable of igniting a dust cloud with a minimum ignition energy greater than 20 m J to 30 m J. In a non-conducting container, relaxation.

may be slower and a discharge to earth would be potentially more incendive depending upon the resistivity of the container.

High resistivity powders do not dissipate their charges by conduction when they enter a container whether or not the container is conducting. Low energy air discharges occur from the bulking point (where the particles first contact the heap) to the wall of the container. However, the energy readily available to such a discharge by conduction within the powder is limited, and experience so far is that this type of discharge to the walls of the container does not ignite dusts with minimum ignition energies greater than 20 m J to 30 mJ. There may be a scale effect whereby the longer discharges possible in a large container are more energetic.

11.3.4 *Discharges from Solids and from Personnel*

Insulated conductors in powder handling systems are readily charged by contact electrification. For example, an isolated length of metal pipe or ducting can be charged to a high potential by the flow of powder through it and is then capable of energetic sparking to earth. Powders, in suspensions or in bulk, can also charge insulated conductors in their vicinity by induction or by sharing charge with them. Thus, the pouring of a powder into an unearthed metal container can result in a spark from the container dissipating a charge equivalent to the total charge accumulated inside the container.

It is a feature of certain types of powder processing operations that personnel come into close contact with the powders, for example, when sampling or during transfer of powder from one container to another. If the person concerned is not earthed he constitutes an insulated conductor and can collect a significant charge by induction or charge sharing.

Non-conducting solids and containers in contact with charged powders are potentially hazardous. It is possible in some circumstances for a highly energetic propagating brush discharge to occur. This subject is dealt with in more detail in 12.2.3.

11.4 Precautions **Against Static Electricity from Powders**

11.4.1 General

When an ignition risk exists in a powder handling system, the precautions needed to avoid a static electricity hazard depend, to some extent, on the presence of other potential ignition sources in the system. If the latter necessitate explosion protection (for example, explosion vents, an explosion suppression system or inert gas), then precautions against electrostatic ignitions can often be limited to the earthing of metal components and, where appropriate, personnel, because the energies of discharges from non-conductors in thd system are likely to be comparatively low and incapable of igniting the powder. This does not apply, however, if a mixture with a minimum ignition energy is present, such as a flammable gas mixture; an example is the pouring of a powder into a flammable solvent. Earthing of plant and personnel is also effective in avoiding physiological shocks.

Earthing and bonding are considered in detail in Section 4. In the handling of powders, the presence of the powder itself can increase the resistance to earth of metal components and it is necessary, therefore, ensure that earthing is adequate when the plant is dirty as well as when clean. This applies particularly to floors.

When further precautions are considered necessary, control of both generation and dissipation of charge should be considered.

11.4.2 *Control of Charge Generation*

Systems handling powders are less amenable to design for the control of static electricity generation than those handling liquids because the details of the process are often determined by factors such as the flow properties of the powder, which can rarely be modified enough to have a significant effect on charge generation. With high resistivity powders, some reduction may be possible by using high density (semi-bulked) flow rather than low density flow. However, control of charge generation can seldom be used as the primary means of minimizing static electricity risks in powder handling systems.

11.4.3 *Charge Dissipation*

11.4.3.1 *Humidification*

Normal atmospheric air is a poor conductor of electricity irrespective of its relative humidity. Humidification is, therefore, ineffective as a means of dissipating the charge from a dust cloud of any kind.

High relative humidity is capable of decreasing the surface resistivity of many powders and hence. of facilitating charge relaxation in the bulked powder when in an earthed metal container. However, for hydrophobic materials, a relative humidity well in excess of 70 percent RH may be needed and it is often impracticable to operate powder processing units at this high level of humidity.

11.4.3.2 *Ionization*

The electrical conductivity of the gas in which a powder is suspended can be increased by ionization, produced either by corona discharge from pointed conductors or by the use of radio-active sources. In practice, however, such systems are not widely used for removing the charge from powders except, occasionally, for preventing dust deposition on surfaces. It is difficult to provide the ionization required throughout the relatively large volume of dust cloud enclosures owing to ion losses and recombination. Also, the total charge to be dissipated is often greater than the change that can be transferred by a radio-active ionization system. Similar considerations apply to the use of ionization for removing charge from bulked powders.

Localized discharges from pointed, earthed, conducting probes or wires can be of value in both dust clouds and bulked powders when the surface charge density approaches $10 \mu C/m^2$ and the electric field strength is close to the breakdown value, a situation likely to be encountered with high resistivity powders. Such earthing probes or wires placed at the bulking point as a powder enters a container can reduce the energy of individual discharges to a low level. If the powder enters a non-conducting container it can also provide a safe route to earth for the accumulating charge, thereby avoiding propagating brush discharges (see 12.2.3).

Where substances with very low minimum ignition energies are involved, for example, hydrocarbon gases, it is difficult, in large containers, to avoid incendive discharges by means of rods and wires. The ignition problem should then be dealt with by other means, such as inert gas or explosion venting; if necessary, rods can be used in these systems to avoid physiological shocks.

11.4.3.3 *Antistatic additives*

In the case of powders there is no equivalent to the antistatic additives available for reducing the resistivity of liquids. Such additives are used in the case of solid polymers but are not-normally present at the stage when these materials are being handled as granules.

12 ELECTROSTATICS IN HIGH RESISTIVITY SOLIDS

12.1 Charge Generation

Non-conducting materials are being used increasingly in equipment and structures in a multiplicity of forms including pipes, containers, sheets, coatings and liners. This subclause is concerned with those having volume and surface resistivities in excess of about $10^{12}\,\Omega m$ and $10^{12}\,\Omega$, respectively, and, therefore, capable of retaining charge for long period (relaxation time greater than about 20 seconds). Most synthetic polymers fall into this category.

These materials are readily charged by contact electrification and also by sharing charge with other charged bodies. The contact electrification is often a consequence of process in which the materials is being used; for example, the pneumatic transfer of a powder or the flow of a liquid through a plastics pipe generates charge on the inner surface of the pipe. Alternatively, the charging can be due to something extraneous to the operation, such as rubbing of the external surface of a-plastics pipe. Charge sharing is often associated with the introduction of charged powder into a high resistivity container and the sharing process then involves discharges from the powder to the container.

Owing to their very high resistivities, the maximum charge that can be retained on these nonconductors is determined not by conduction, but by the breakdown strength of the atmosphere adjacent to the charged surface. Theoretical considerations indicate that when the surface is remote from earthed metal the maximum charge density in air at normal temperatures and pressures is about $30 \mu C/m^2$. The precise maximum depends on many factors including the shape of the surface,

In the case of extended sheets of a high resistivity non-conductor, the charge density for breakdown depends on whether there is earthed metal either near or in contact with the side of the sheet opposite that where the charge resides. In the absence of metal, the field due to the charge is directed outwards from the sheet roughly equally on both sides, as shown diagrammatically in Fig. 3 (a). The presence of earthed metal behind the sheet causes a redistribution of the field so that much of it is directed towards the metal, leaving less going outwards from the surface. This is illustrated in Fig. 3 (b), where the density of the arrows is an indication of the field strength. In these circumstances a charge density much greater than $30 \mu C/m^2$ can be accommodated on the non-conductor surface before discharges commence. The field outwards from the surface is least when the sheet is in contact with the metal as a coating or liner [see Fig. 3 (c)] and the maximum charge density before discharge is correspondingly greater. This maximum charge density increases as the thickness of the coating or liner becomes less.

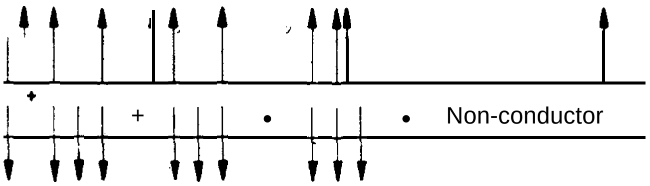
12.2 **Discharge Involving High Resistivity Materials**

12.2.1 *General*

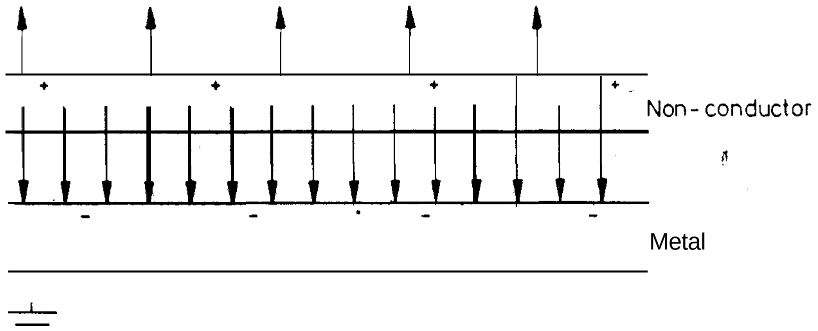
Charged high resistivity materials can give rise to discharge either directly from their surfaces or through the agency of insulated conductors, by induction or charge sharing.

The usual type of discharge from a high resistivity surface is a brush discharge as described in 6.3. The diversity of discharge characteristics and the state of knowledge concerning them are such that no general quantitative measure is available of the incendivity of the discharge. The form of the discharge depends on the design of the equipment in which the material is incorporated, more particularly on the proximity of earthed matallic structure.

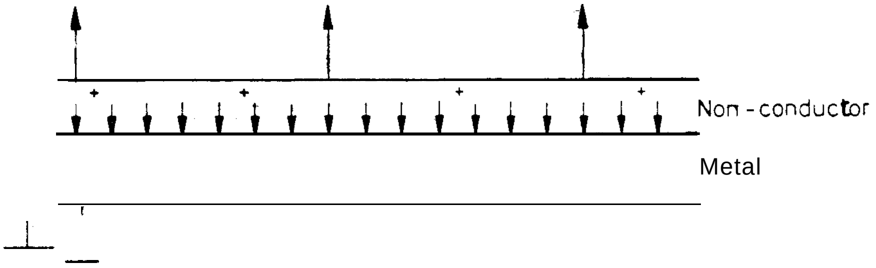
A number of cases are considered in 12.2.2 to 12.2.6.



(a) Isolated sheet



(b) Sheet with adjacent earthed metal at rear



(c) Sheet backed by earthed metal

FIG. 3 THE ELECTRIC FIELD DUE TO A CHARGED SHEET OF A HIGH RESISTIVITY NON-CONDUCTOR

12.2.2 ***Surfaces Remote from Earthed Metallic Structure***

It is known that brush discharges from high resistivity surfaces can ignite flammable gas mixtures with minimum ignition energies less than about 4 mJ. Mixtures with greater minimum ignition energies can be ignited in some circumstances. For example, contamination may make the surface more conductive so that it behaves as a conductor and the total charge in the contaminated area can then be released as a spark to earth which may be highly incendive.

12.2.3 ***High Resistivity Non-conducting Containers Near Earthed Metallic Structure***

In addition to the types of discharge mentioned in **11.2.2**, the much more serious hazard associated with propagating brush discharges may be encountered when a container made of high resistivity material is mounted close to an earthed metal structure in a powder handling system. As the container is filled with highly charged powder, discharges occur from the bulking point of the powder to the inside surface of the container, and from the metal structure to the outside of the container. This leads to polarization across the wall of the container with consequent very high surface charge density and stored. energy density. The container wall in effect acts like the dielectric of a charged capacitor. A propagating brush discharge (see 7.4) can then occur if an earthed conductor or person approaches the interior surface, for example, to clean it.

12.2.4 ***High Resistivity Non-conducting Coatings on Metals***

The risk of an incendive discharge from a thin high resistivity non-conducting coating on an earthed metal surface is usually less than that from an isolated thin sheet of a similar material. As described in 12.1, a greater surface charge density is required to initiate a discharge from the coating and the form of the discharge is likely to be less incendive because of the smaller discharge gap and the smaller area from which charge can be drawn.

The probability of an incendive discharge depends on the surface charge density and on the thickness of the coating, becoming less as the coating becomes thinner.

A completely safe thickness cannot be specified, but very thin layers, such as paint films and thin epoxy coatings, are unlikely to present a hazard. Often these very thin films break down electrically before a hazardous surface charge density is reached, allowing the charge to flow to the earthed metal backing.

If the charge density is very high and electrical breakdown does not take place across the coating, the approach of an earthed conductor may precipitate a propagating brush discharge liberating virtually all the energy stored in the polarized coating.

It is also known that the separation of a high resistivity non-conducting coating from its substrate metal can cause incendive discharges between the two. The same type of discharge can also occur when a high resistivity liner is removed from an earthed metal container.

Another consequence of the comparatively small field outwards from a thin coating on earthed metal is that it is much less likely to attract dust than a similar isolated film.

12.2.5 *High Resistivity Non-conducting Films*

Polymer films readily acquire charge whilst being processed and this is particularly troublesome when the film is wound on to a reel. Personnel approaching the reel can experience shocks and the discharges are capable of igniting flammable gas mixtures. The breakdown value of the atmotphere limits the surface charge density, which rarely exceeds $10 \mu C/m^2$. Discharges to the atmosphere leave charge patterns on the film surface, known as Lichtenberg figures, which involve high positive and negative charges adjacent to each other. The resultant fields can anchor dust to the surface.

Occasionally film acquires polarization charges, that is, equal and opposite charges on the two surfaces of the film. Although such charges may reach higher surface densities than the usual single surface charges, they do not give additional problems in most circumstances.

12.2.6 *Insulated Conductors*

Both unearthed metal plant and unearthed personnel near charged high resistivity non-conducting components or structures can be charged by induction or charge sharing and they are then sources of incendive sparks to earth. The close proximity of a charged high resistivity non-conducting material to an insulated conductor is highly dangerous because it combines the possibility of the long-term retention of a large amount of charge with the possibility of virtually all of the stored energy being released as a highly incendive spark.

12.3 Precautions Against Discharges from High Resistivity Solids

12.3.1 *General*

The occurrence of discharges from high resistivity materials can, in principle, be avoided by either minimizing the generation of static electricity or encouraging its dissipation. In practice, the measures that can be taken are mostly in connection with charge dissipation; the principal measures are considered in 12.3.2 to 12.3.6.

12.3.2 *Reduction of Resistivity*

Many items fabricated from polymeric materials; for example, rubbers, are being made available commercially in conducting forms by the incorporation of suitable additives, such as carbon black.

The resistivity required to prevent the retention of charge and the production of undesirable effects depends on the nature of the effect, for example, whether it is dust contamination or ignition risk, and on the rate of accumulation of charge on the material. -Surface and volume resistivities below about 10s Ω and $10^6 \Omega m$ respectively, are generally regarded as producing no undesirable effects except possibly in relation to explosives. In many applications, however, surface and/or volume resistivities below about $10^{11} \Omega$ and $10^{10} \Omega m$ respectively, may be sufficient under normal ambient conditions.

12.3.3 *Humidification*

With many materials, including cotton, cellulose acetate, paper and gelatin, increased humidity brings about a marked reduction in resistivity and is helpful in reducing electrostatic effects. Many polymeric materials, however, are highly hydrophobic and with these it would be necessary to raise the relative humidity to the impracticably high levels of 80 percent RH or even 90 percent RH to ensure reliable relaxation of charge to earth.

12.3.4 *Ionization*

It is possible to assist the neutralization of the charge on the surface of high resistivity materials by ionization of the atmosphere near the charge. As usual with this technique care is required in the presence of substances with low minimum ignition energies, such as flammable gas mixtures, but it is valuable in avoiding shocks to personnel.

An important application of ionization is in the handling of high resistivity films. The following three types of static eliminator based on ionization are available:

a) ***Passive*** — Corona discharges from earthed sharp needles, fine wires or conductive tinsel in the field of the film provide ions to neutralize the charge on the film. A disadvantage of the passive eliminator is that the charge density on the film has to reach a threshold before it can operate, and this threshold is too high for complete safety unless the device is sited well away from earthed metalwork which attracts a significant proportion of the field originating on the film. It may, however, be used safely in flammable mixtures with minimum ignition energies greater than about 0·2 mJ, but not in more sensitive, for example, oxygen enriched, atmospheres.

b) ***High Voltage*** — Ionization at a needle tip is produced by applying a high voltage to it; commercial systems commonly used a 5 kV to 10 kV mains frequency supply to a row of points. There are 'shockless' versions which are safe to touch and encapsulated designs, some of which are intended for use in flammable atmospheres, but expert advice should be obtained before employing such devices in this situation.

c) ***Radio-activity*** — Ionization is produced by means of a radio-active source; the maximum ion current is usually quite low. Radio-active ionization itself does not present an ignition hazard, but discharge to the installation are possible which necessitate precautions in flammable atmospheres. Passive eliminators are often used for this purpose.

For dissipating charges from awkwardly shaped objects, ionized air blowers using either high voltage or radio-active sources are available.

12.3.5 *Earthing*

The earthing and bonding of metalwork are dealt with in general in Section 4. Particular care is needed in systems incorporating metals and high resistivity non-conductors. Components whose earthing could be overlooked are, for example, a length of metal pipe suspended between two sections of non-metallic pipe, the internal metal wire reinforcement in a non-metallic hose, wire mesh wrapped around pipe cladding, and small components, such as valves, insulated by high resistivity packing materials.

Dangerous discharges involving high resistivity containers can be avoided by earthing their contents. In the case of liquids, this should be done by means of an earthed plug at the base of the container, or by any earthed metal reaching near to the bottom (see 10.3.3.1). Even so, a risk may remain, associated with charge on the wall of the container. In the case of powders the technique, described in 11.4.3.2, of applying earthed rods or wires at the bulking point is effective. However, this method involves ionization and should not be used in the presence of flammable gas mixtures or sensitive dust clouds.

12.3.6 *The Use of Earthed Metal Meshes*

A degree of protection against static electricity can be achieved by incorporating an earthed metal mesh mto a high resistivity material or by wrapping such a mesh arpund its surface.

An internal mesh permits the flow of some charge to earth but the high resistance of the non-conductor keeps the rate of charge transfer at a low level. The mesh does, however, increase the capacitance of the system so that more charge is needed to produce a breakdown field at the surface. Improved safety is, therefore, the result of control of field strength rather than of earthing.

An earthed wire mesh on the surface provides a path to earth for charge, but with highly charged materials the transfer of charge to the mesh probably involves corona discharges. In a properly designed system these discharges are unlikely to be incendive to most flammable mixtures, but the possibility of their igniting more sensitive mixtures cannot be ignored.

With both internal and external meshes a failure to earth the mesh may result in a high energy discharge. The use of meshes in conjunction with high resistivity non-conductors is best considered on an individual basis and not as part of normal earthing procedures.

13 STATIC ELECTRICITY IN GASES

13.1 The movement of pure gases or of a mixture of gases, such as the atmosphere, generates little, if any, staticelectricity, Gases can, however, carry electrostatic charges on suspended liquid or solid particulate matter and it is with charges of this type that this clause is concerned. The particles may be extraneous matter, such as dust or water droplets, or they may be a condensed phase of the gas itself, such as carbon dioxide 'snow', liquefied gas mists or the droplets in wet steam.

Charging is due to contact electrification of the particles, and separated charge may, therefore, be left on items of equipment, for example, pipes or nozzles, with which the gas makes contact. The particles in the gas may also share their charge with any object on which the gas impinges, and the gas stream may induce a potential on any insulated conductor in its vicinity.

Examples where extraneous matter is involved are the charging of the nozzles of large industrial vacuum cleaners and of pipework in systems used for the pneumatic transport of small articles. Ignition of flammable mixture and serious shocks to personnel are both possible unless the equipment in question is made of metal and earthed. The pneumatic transport of powders is a particular case of the carriage of charge by gases where the particulate matter is present at a comparatively high concentration, this has been considered in detail in 11.

13.2 The escape or release of any compressed gas containing particulate matter, for example, jets of compressed air carrying water or dust issuing from orifices, valves or flange leaks, is potentially hazardous. Because of their low minimum ignition energies, the release of hydrogen/air or acetylene/air mixtures requires particular care if they contain entrained particles.

The release of liquefied carbon dioxide results in a mixture of the gas and carbon dioxide snow which can be highly charged; potentials up to 12 kV have been measured on the nozzle and on an insulated metal object on which the gas stream impinges. This could be a hazard when using carbon dioxide for inerting if suitable precautions are not taken. Liquefied petroleum gases (LPG), such as liquid propane, are similar to carbon dioxide in that they form a mist as they are rapidly expanded. LPG is normally handled in closed systems where there is no release to the atmosphere and the gas concentration within the system is always well above the upper flammable limit. However, flammable concentrations can occur outside the system, for example, during the filling of liquid propane bottles.

In all systems handling gas the main precaution is to bond together and earth all metallic equipment in the system and also any metallic parts on which the gas may impinge outside the system. The use of non-conductors should be avoided where there is any possibility that they could retain charge, either generated on them by contact electrification or imparted to them by a gas stream in their vicinity.

14 STATIC ELECTRICITY ON PERSONNEL

14.1 Charge Generation

The volume resistivity of the human body is low enough for it to act as a conductor. If a person insulated from earth becomes charged, therefore, he can give rise to sparks which may be sufficiently energetic to ignite flammable mixtures or to cause electric shocks to himself or others. His insulation may arise because he is wearing insulating footwear or because he is standing on an insulating floor. The body can be charged by contact electrification, or by induction or charge sharing involving other charged objects or, more particularly, the clothing being worn.

Examples of charge generating mechanisms are:

a) rising from a chair or brushing against a wall (the initial charge separation is between the outer surface of the clothing and the other surface involved; the body is the ncharged by induction);

b) walking on an insulating floor, such as a carpet made of high resistivity material (the initial charge separation is between the floor and the footwear, and the body is then charged by sharing in case of conducting footwear, or by induction in the case of insulating footwear);

c) removal of an outer garment, where the contact electrification is between the inner and outer layers of clothing and the body is then charged by sharing or by induction;

d) pouring of liquids or powders from a container held by a person (the liquid or powder carries away charge of one polarity leaving an equal and opposite charge on the body) ; and

e) contact with charged material, as when sampling a highly charged powder.

When there is a continuous charge generation process, the maximum body potential is limited to about 50 kV by electrical leakage and sparking.

14.2 Discharge Involving Personnel

14.2.1 *Sparks from the Body*

The total stored energy on a charged person is given by the expression $\frac{1}{2}CV^2$ as derived in 7.1. A typical body capacitance is in the range 100 pF to 300 pF. Not all the energy stored on the body is released in the spark discharge, the amount depending on the circumstances of the discharge. Consideration should be given to the need for precautions when the minimum ignition energy is less than about 100 m J, for example, in the presence of flammable gas mixtures and sensitive dust clouds.

14.2.2 *Sparks from Clothing*

It will be seen from 14.1 that in many cases clothing becomes charged, but there is little chance of serious sparking direct from clothing if the wearer is earthed, because only a small proportion of the field due to the charged clothing is directed outwards from the person. Also sparks from clothing are limited by the resistivity of the material. Consequently, the energy of any discharge is small and unlikely to be dangerous except in atmospheres with very low minimum ignition energies, as when enriched with oxygen, or in handling explosives.

If an article of clothing is removed, however, its charge is more readily available and a dangerous spark is more likely to occur, either directly or by induction from it.

14.3 Precautions Against Static Electricity on Personnel

14.3.1 *Discharges from the Body*

Static electricity discharges from a person can be minimized by providing an adequately conducting path between the person and earth through his footwear and the floor. Leather soled footwear is usually sufficiently conductive for this purpose in normal humidity conditions, although it may fail if very dry.

Electrically conducting and antistatic footwear are both effective, provided that the floor does not impede the dissipation of charge. Antistatic footwear is intended for use in situations where protection is also required against dangerous electric shock in the event of apparatus becoming defective when operating at voltages of up to 250 V to earth; conductive footwear is for use where there is no such danger of electric shock. The resistance of both types of footwear may increase in use and, in addition, insulating layers, for example, of oil or wax, can be formed on their soles. The footwear should therefore be tested regularly,

14.3.2 *Discharges from Clothing*

In general, clothing made from any material can be worn provided that the wearer is earthed either directly or through approved antistatic or conducting footwear and floors. Exceptions are in areas where explosives are handled, where there are highly flammable gas mixtures (for example, oxygen-enriched atmospheres) and in, the manufacture of solid state devices. In such cases garments made of high resistivity materials should not be worn, and conductive outer garments should be earthed. Clothing can be made conductive by treatment with antistatic agents, but the effect of some of these is temporary and they should be re-applied at regular intervals, at least after each washing. Many antistatic agents, and also conductive clothing made from natural fibres such as cotton, flax or linen, rely on the presence of atmospheric moisture.

Clothing should not be removed in areas where flammable gas mixtures or low minimum ignition energy dust clouds are present (*see* 14.2.2).

SECTION 3 EARTHING AND BONDING

15 EARTHING AND BONDING

15.1 General

The most common source of danger from static electricity is the retention of charge on a conductor, because virtually all the stored energy can be released in a single spark to earth or to another conductor. The accepted method of avoiding the hazard is to connect all conductors to each other and to earth by electrical paths with resistances sufficiently low to permit the relaxation of the charges. Similar earthing and bonding techniques are also associated with electricity power supply systems and lightning protection installations, although the criteria for their design are not necessarily the same. The present discussion is concerned only with protection against static electricity.

15.2 Criteria for the Dissipation of Static Electricity from a Conductor

15.2.1 *Basic Considerations*

The maximum resistance that will prevent the retention on a conductor of a dangerous amount of charge depends upon the rate at which the conductor is receiving charge. The same principle apply to both earthing and bonding; the condition that has to be satisfied in all cases is that the total resistance to earth should not exceed an acceptable maximum.

In electrical terms, the majority of situations is adequately represented by the circuit shown in Fig. 1, where R is the resistance to earth from the conductor. As stated in 6 and 7 the maximum potential and the maximum stored energy on the conductor are:

$$V_{\max} = IR$$

$$\text{and } E_{\max} = \tfrac{1}{2} C V^2_{\max} = \tfrac{1}{2} C I^2 R^2$$

where the symbols have the meanings assigned to them in 6 and 7.

An incendive discharge occurs when two conditions are satisfied. These are: that the potential of the conductor reaches a value such that the associated field strength exceeds the breakdown strength of the atmosphere, and that the energy released in the spark exceeds the minimum ignition energy of any flammable material present. With few exceptions, earthing installations. are intended to prevent all discharges that could be incendive, and the first of these conditions is, then, the one to be satisfied, irrespective of spark energy. That is, $IR <$ potential required to initiate an incendive discharge.

A potential of at least 300 V is considered to be necessary to initiate an incendive discharge in normal industrial operations, but in explosive manufacturing plant, 100 V is considered to be hazardous. Taking the latter figure, therefore, the requirement for the safe dissipation of static electricity is:

$$R < \frac{100}{I} \ \Omega$$

15.2.2 *Practical Criteria*

In the development of earthing specifications,. each situation, that is, each individual value of I, cannot be considered separately. It is known that charging currents range from 10^{-11} A, to 10^{-4} A, and the corresponding values of R are $10^{-13}\,\Omega$ and $10^6\,\Omega$. Taking the maximum value of I leads to the conclusion that a resistance to earth of $10^6\,\Omega$ will ensure safe dissipation of static electricity in all situations. In most industrial operations I does not exceed 10^{-6} A and a resistance to earth of $10^8\,\Omega$ is, therefore, safe in many situations.

Conductors in good contact with earth have a resistance to earth far less than $10^6\,\Omega$ and, for practical convenience, a much lower resistance is. often specified as the maximum permitted earthing resistance. The following are amongst the factors to be considered in choosing a resistance value for this purpose.

a) The resistance between metals in good contact rerely exceeds a few ohms. A value. less than 100 Ω is readily attainable and is unlikely to deteriorate with time to a level above $10^6\,\Omega$ unless the plant is subject, for example, to serious corrosion.

b) Resistances of the order of thousands of ohms across apparent metal/metal contacts suggest contamination by corrosion products. or paint and there is some risk that the resistance might in time rise above $10^6\,\Omega$.

c) The resistance specified to avoid static electricity hazard should be compatible with that required for other reasons. In order to provide protection against lightning or to meet the requirements for earthing associated with an electricity power supply system, resistance to earth as low as 1 Ω may be needed. IS 3043-1987 should be consulted for details of the precise requirements.

For reasons such as these, and for convenience in monitoring, maximum resistance to earth in the range 10 Ω to 100 Ω have been specified for electrostatic earthing system for conductors. The particular value chosen is, to a degree, an arbitrary one. 10 Ω has the advantage of being equal to the value prescribed for lightning protection of existing plants and will be used in the remainder of this discussion. A clear distinction should, however, be made between a value such as this, chosen for reasons of practical convenience, and the value of 10^6 Ω which is in fact the upper limit for the resistance to earth of a conductor.

The criterion of 10 Ω is generally suitable for wholly metallic systems but cannot always be applied to systems involving non-metallic (such as plastics) components, which are becoming increasingly common. Requirements for earthing are, therefore, now required to cover a variety of different situations. A number of possibilities are considered in 15.3 and 15.4.

15.3 Earthing Requirements in Practical Systems

15.3.1 *All-Metal Systems*

15.3.1.1 Fixed structures

The main structure of a metal plant and the major components mounted on it such as reactors, mills, blenders or tanks, and also items such as pipelines, are permanent installations normally with bolted or welded joints. They are usually in direct contact with the electricity power supply earthing system and their resistance to earth to protect against lightning should, where applicable, be less than 10 Ω. There is, in general, no difficulty in establishing and maintaining a resistance to earth of 10 Ω or less, and there is little risk of this deteriorating to a value above 10^6 Ω. For these reasons a prescribed maximum resistance of 10 Ω is acceptable to avoid static electricity hazards and, in most instances, this will be achieved without special earthing connections. These connections are to be recommended only when the plant design and usage make it difficult to maintain a low resistance to earth without them.

Plants are being developed which incorporate major items not in direct electrical connection with the main structure, for example, items on flexible or vibratory mountings or on load cells. These should have special earthing connections to ensure a resistance to earth below 10 Ω, unless a higher prescribed resistance can be accepted (see 15.3.2).

A pipeline is sometimes a temporary installation possibly less well connected to the structure of the plant and incorporating lenghts of non-conducting pipe. In such cases special earthing connections may be needed.

In the past, the use of bonding connectors across all joints in a metal pipeline has been recommended in some guidelines. The general application of this principle can cause practical difficulties and such bonds should be used only when the design is such that the 10 Ω criterion may be exceeded.

15.3.1.2 *Transportable metal items*

These are items of equipment, including drums and road and rail tankers, which cannot be permanently connected to earth through the main plant structure. In many cases, their resistance to earth may be well below 10^6 Ω, but, for example, when standing on the dry concrete floor or on pneumatic tyres, it may not be adequately controlled and may well rise above 10^6 Ω in use. To meet this situation, the resistance to earth of these types of equipment should be kept below 10 Ω by the provision of suitable earthing connections. The minimum essential requirement is that such earthing should be in position at any time when a flammable mixture may be present and the item may retain an electrostatic charge, such as during the filling or emptying of a' container with a flammable liquid.

15.3.2 *Metal Plant with Non-conducting Elements*

Plant of metal construction has always contained some non-conducting items which could affect electrical continuity and earthing. Examples are lubricating oils and greases, and more recently, components made of high resistivity non-conductors such as polytetrafluoroethylene or polyethylene. Normally, all metallic parts of the plant are earthed either directly or through suitable earthing connections and all paths to earth have resistances less than 10 Ω. Problems arise when this solution presents difficulties owing to the design of the equipment in question.

As already mentioned (see 15.2.2) a resistance to earth of less than 10^6 Ω (or more generally $100/I$ Ω) is adequate for the relaxation of static electricity, and in many cases advantage can be taken of this. An important example is the oils and greases used in the lubrication of rotating shafts, stirrers, etc. In the past the use of conducting brushes pressing on rotating shafts has beer recommended, but they are difficult to adjust and maintain and their long-term effectiveness is doubtful. Tests have shown that the resistance across a lubricating film in a bearing is unlikely to exceed 10^3 Ω, so that it is in Fact capable of dissipating static electricity without special earthing devices. The same approach can be applied to other plant items where the resistance to earth is less than $10^6\,\Omega$ but where a 10 Ω limit is difficult to achieve, such as roller conveyors or scroll feeds. In such cases a maximum resistance to earth of $10^6\,\Omega$ can be specified provided that:

a) the resistance calculated using the volume resistivity of the non-cunductor and the dimensions of the leakage path is less than $10^6\,\Omega$, and

b) tests made in normal operations are in reasonable agreement with the calculations and indicate that the resistance will remain stable and less than $10^6\,\Omega$.

This approach removes the need for many special earthing devices to meet a 10 Ω criterion and enables effort and resources to be concentrated on situations where such a level of resistance to earth is justified.

When high resistivity polymers are involved as the insulating elements, a resistance in excess of $10^6\,\Omega$, is almost inevitable and the only solution is to provide an earthing connection between the isolated conductor and adjacent earthed metal components. The appropriate maximum resistance would be 10 Ω. Examples are ball valves with polytetrafluoroethylene packing and seals, pipe spacing rings insulated by polytetrafluoroethylene coated gaskets, isolated metal pipeline sections between plastics connectors and metal nozzles at the end of plastics lines.

A major problem is the detection of plant items which may be insulated. In many cases a non-conducting component within a piece of equipment is not visible and may not be detected by external resistance testing. It is essential that any design change involving the incorporation of non-conducting materials- should be studied in detail to ascertain whether its presence will cause the insulation of any metallic component.

15.3.3 ***High Resistivity Non-conducting Materials***

Materials such as glass and high resistivity polymers are increasingly being used as major items of equipment. The considerations in 15.2 concerning the&appropriate criteria for resistance to earth to avoid electrostatic hazard can be extended to these materials. The basic condition to be satisfied is that the resistance (in ohms) to earth from every part of the non-conductor should be less than $100/I$. However, the provision of the large number of closely spaced contacts with earth required to meet this condition is impracticable, and the non-conductors will, therefore, retain their charge for long period.

The discharges from high resistivity non-conductors are of comparatively low energy, although they • may be sufficient to ignite sensitive flammable mixtures. In practice, however, there may be surface contamination with a conducting material, such as water, and if this does not cover the whole surface and is not in contact with earth, it constitutes an insulated conductor which can be the source of a high energy spark. Also, these non-conducting systems often contain metal components which will give rise to sparks if not earthed. Examples are the connecting bolts and backing flanges in a plastics pipelines and the metal mesh extending throughout some types of non-conducting wall cladding.

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

Ideally, all isolated conductors in a non-conducting system should be earthed, but effective earthing in many cases requires the extensive use of special earthing devices and an unrealistic degree of inspection and maintenance. The general recommendation that all conductors in high resistivity non-conducting systems should be earthed in, therefore, open to question. The measures taken to maintain safety will depend on the individual installation, and no general earthing specification can be prescribed.

Lack of earthing alone is not sufficient to produce an ignition. The risk depends also on:

a) the probability that the non-conductor will become charged,

b) the probability of an incendive spark from conductors, and

c) the probability of a flammable mixture being present.

Condition (c) can be considered in terms of the hazardous areas developed in connection with flammable gases and defined in 4 for convenience, the same concept is taken here to apply also to dusts.

The overall principle adopted is to evaluate the probability of an ignition induced by static electricity and by means of the techniques most appropriate to the system in question, including earthing, to reduce this probability to a level no greater than that from other sources of ignition, for example, electrical equipment, and also to a level acceptable to the user. In zone 0 or zone 1 areas this necessitates the elimination of the static electricity hazard by preventing generation and retention on both non-conductors and conductors by whatever technique is appropriate; the avoidance of the flammable mixture by inerting should also be considered. In nearly all cases earthing in some form would be involved.

However, in a zone 2 area, if static electricity is very improbable, the overall ignition probability may be so low that earthing of isolated conductors in non-conducting systems solely for the control static electricity can be dispensed with.

15.3.4 *Conductive and Antistatic Materials*

Materials are increasingly becoming available which combine the desirable properties of polymers, such as corrosion resistance with a low enough volume resistivity to prevent the retention of dangerous levels of static electricity, provided that they are in contact with earth (see 12.3.2). A resistance to earth of the order of 10 Ω is not applicable. The basic requirement is for a resistance (in ohms) to earth of less than $100/I$ and this is often in the range of 10^4 Ω to 10s Ω. For general use a maximum value of 10^6 Ω is probably the most appropriate, but if it cannot be met, $100/I$ would be acceptable. Values above 10^8 Ω, however, are acceptable only in special circumstances after assessment of the hazard.

15.3.5 *Summary of Earthing Requirements*

For practical convenience, an appropriate value for the maximum resistance to earth from all parts of fixed metal equipment is 10 Ω, although a resistance up to 10^6 Ω can be accepted, provided that it can be maintaned. Special earthing connections are not normally required, unless, for example, equipment is mounted on insulating supports, or if high resistivity contamination may develop across a joint.

Transportable metal items should have a resistance to earth of 10 Ω or less, provided by a special earth connection.

The use of high resistivity materials (polymers) for the construction of plant for use in the presence of flammable mixtures is not generally recommended and should rarely be encountered. No generally applicable resistance value to earth can be suggested and safety measures should be developed for each individual plant to reduce the hazard to an acceptable level. In a zone 2 area where the risk of electrostatic generation is sufficiently low, earthing of metal components solely for the control of static electricity may not be necessary.

Antistatic or conductive type materials can be used to avoid the retention of static electricity. The most appropriate maximum value for the resistance to earth form all parts of such equipment is 10^6 Ω although values up to 10^8 Ω may be acceptable in some cases.

A brief review of earthing resistance recommendations is given in Table 4.

15.4 The Establishment and Monitoring of Earthing Systems

15.4.1 *Design*

At the design stage, the plant should be examined to ascertain the possible electrostatic hazards, and the earthing requirements should be determined using the guidance given in 15.3. Where no other form of earthing exists it should be achieved by connections to copper rods or plates driven into or buried in the ground. However, special earthing devices, such as bonding cables, straps or brushes should be kept to the minimum essential. Where they are required, cables or straps to meet the 10 Ω maximum resistance criterion should be connected to threaded studs or bosses welded or brazed to the metal work of the structure.

Important features in the design of earthing devices are:

a) they should be recognized as such and accepted as essential to the safe operation of the plant;

b) they should be robust and should be sited so that they are not affected by high resistivity contamination, for example, by corrosion products or paint;

c) they should be clearly visible, or else essential to the correctfunctioning of the plant, so that any shortcoming is quickly detected;

d) they should be easy to install and to replace; and

e) cables for earthing transportable items should be equipped with a robust clip capable of penetrating through paint or rust layers. The clip should be attached before the operation commences and should remain in place until it has been finished and all dangerous electrostatic charges have been eliminated.

15.4.2 *Monitoring*

The checking of earthing as a protection against static electricity should be recognized 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 resistance between the different parts of the plant and earth, but it is important that this should be supplemented by visual inspection. This will help to detect any incipient malfunction of the earthing devices and to minimize the risk of modifications leading *to the insulation of a conductor.

Where resistances to earth greater than 10 Ω are permitted, the stability of the resistance is a critical feature. The monitoring system should be capable not only of monitoring these higher resistances but also of bringing to light any changes of resistance.

Table 4 Summary of Recommended Earthing Resistances for the Control of Static Electricity

(Clause 15.3.5)

Ref Clause	Type of Installation	Electrical Area Classification	Recommended *Max* Resistance to Earth, Ω	Comments
15.3.1.1	Main metal plant structure	Zones 0,1,2	10	Earthing normally inherent in the structure
15.3.1.1	Large fixed metal plant items (reaction vessels, powder silos, etc)	Zones 0,1,2	10	Earthing normally inherent in the structure. Occasionally items may be mounted on non-conducting supports and special earthing connections may then be required
15.3.1.1	Metal pipelines	Zones 0,1,2	10	Earthing normally inherent in the structure. Special earthing connections may be required across joints if there is doubt that the 10 Ω criterion will be satisfied
15.3.1.2	Transportable metal items (drums, road and rail tankers, etc)	Zones 0,1,2	10	Special earthing connections are normally required
15.3.2	Metal plant with some non-conducting elements (rotating shafts, stirrers, etc)	Zones 0,1,2	10^6	In special cases a limit of $100/I$ Ω may be acceptable, but in general if a 10^6 Ω criterion cannot be satisfied a special earthing connection should be used to obtain a resistance to earth of less than 10 Ω
15.3.3	High resistivity non-conducting items with or without isolated metal components (for example, bolts in plastic pipeline)	Zones 0,1,2	No generally applicable value	The general electrostatic ignition risk and the fire hazard normally preclude the use of such non-conducting materiale unless it can be shown that significant charge accumulation, earthing is not required in zone 2 areas
15.3.4	Items fabricated from conductive or antistatic materials	Zones 0,192	$10^6 - 10^8$	—

SECTION 4 METHODS OF MEASURING OR ESTIMATING VARIOUS PARAMETERS

16 GUIDANCE ON METHODS FOR MEASURING OR ESTIMATING VARIOUS PARAMETERS

16.0 Introduction

The measures recommended for the control of undesirable static electricity depend to a considerable extent upon a knowledge of particular characteristics of the medium involved, for example, the conductivity of a liquid or resistivity of a powder. In some instances the required information can be obtained from the appropriate manufacturer but, to cover the situation where such information is not readily available, this section has been included in this Code.

Measurements made in flammable atmospheres should be carried out strictly to the requirements of the relevant Indian Standard.

16.1 Electrical Conductivity of a Liquid

16.1.1 *Introduction*

The electrical conductivity of a liquid indicates whether or not it is capable of retaining a hazardous electrostatic charge. For liquids with conductivities above about 10 000 pS/m, the measurement can be made using traditional ac bridge methods. Below this level, such methods are difficult to use and specialized equipment is required. Two methods of measurement are described in 16.1.2 and **16.1.3**, Method A for routine use in the field and method B for more precise measurements in the laboratory.

Low conductivity liquids do not strictly obey Ohm's law, and to obtain reproducible results the conditions of measurement should be carefully selected and controlled. In particular:

a) the liquid should be uncharged at the time of the measurement (if it has been charged, adequate time should be allowed for relaxation and for the establishment of ionic equilibrium; the resultant conductivity is called the 'rest conductivity' meaning that the liquid is electrically at rest, although not necessarily quite motionless);

b) the measurement process should not lead to ion depletion, and significant polarization voltages should not be allowed to develop.

These requirements impose limits on the applied voltage, the electrode spacing and the duration of the test, which may not be as well satisfied in Method A as in Method B.

16.1.2 *Method A, for Routine, Use*

Proprietary instruments are available which are intended for use mainly in the range 50 pS/m to 600 pS/m although some are scaled well below this range. They include instruments for dipping into storage tanks and open containers and for recording continuously the conductivity of liquid flowing in a pipeline. Each should be used in accordance with the manufacturer's recommendations.

Precautions should be taken to avoid sample contamination, which will usually give a high, and hence optimistic, result; errors from this source are more likely at low conductivities, below about 10 pS/m. Contamination is most likely when a sample is transferred from the bulk supply to the instrument by means of a sample bottle or can. If contamination of the container is suspected it should be rinsed several times with a mixture of equal parts by volume of toluene and acetone. It should next be rinsed with n-heptane and finally it should be rinsed several times with the liquid to be tested.

A similar cleaning procedure should be applied to the measuring cell of the conductivity meter if it has been used for testing a high conductivity liquid or has been in contact with aqueous material.

Precautions should be taken to avoid errors due to charge in the liquid resulting from previous movement. For instruments dipped into tanks or open containers, such errors are likely only with very low conductivities; if such errors are suspected, readings should be repeated at five-minute intervals until a constant value is obtained. A continuous conductivity meter should be installed in such a way that:

a) any charge in the liquid is relaxed before it enters the measuring cell, and

b) charge generation due to flow through the cell has a negligible effect on the reading.

This becomes progressively more difficult as the conductivity decreases, and, so far, continuous meters have only been available for conductivities ab-ove 50 pS/m.

The precision of Method A measurements, especially at low conductivities, is expected to be inferior to that of Method B.

16.1.3 *Method B, for Precision Laboratory Use*

16.1.3.1 Summary of method

This is suitable for use with organic liquids having conductivities down to 0·1 pS/m.

A dc voltage is applied to a pair of electrodes in a test cell containing a sample, under such conditions that depletion of ions and polarization at the electrodes are negligible. The maximum current through the cell is measured and the conductivity of the sample is then calculated from the values of the voltage, the current and a cell constant.

16.1.3.2 *Apparatus*

The following apparatus is required:

a) *The test cell* — A recommended design is shown in Fig. 4, for which the cell constant is 1·00 mm ±1 percent. If another cell is used, the electrode spacing should not be less than 1 mm and the voltage gradient across the gap should not exceed 1·6 V/mm; precision will deteriorate as the electrode spacing is decreased. It will be necessary to determine the cell constant using a liquid of known conductivity. If the design of the cell does not provide screening of the liquid, the live electrode and the ammeter input lead, a separate earthed screen should be placed around the cell.

b) *Electrical circuit* — The cell is included in the circuit shown in Fig. 5. The voltage source provides a constant dc voltage which for the cell of Fig. 4, should be in the range 9 V to 11 V. A battery or a well regulated, low ripple voltage supply' is suitable. If the latter is used, line variations should be effectively suppressed, so as to avoid irregular results when measuring conductivities below 10 pS/m.

The voltmeter should be capable of measuring the applied voltage with an accuracy of at least 2 percent and the ammeter should have a lowest measuring range of at most 10^{-12} A full scale deflection,

16.1.3.3 *Procedure*

a) Solvents

1) *Toluene-acetone mixture* — Mix equal volumes of toluene and acetone.

2) *n-heptane* -Prepare by percolating high purity n-heptane (of analytical reagent quality) through 'silica gel. After treatment, the n-heptane should have a conductivity, measured by the present method, of less than 0·03 pS/m.

b) *Preparation of test cell* — The cleaning procedure depends largely on the nature of the sample to be measured. If the sample is believed to contain the same ionic material at the same concentration as the sample measured in the previous test, the cell need only be rinsed a few times with treated n-heptane.

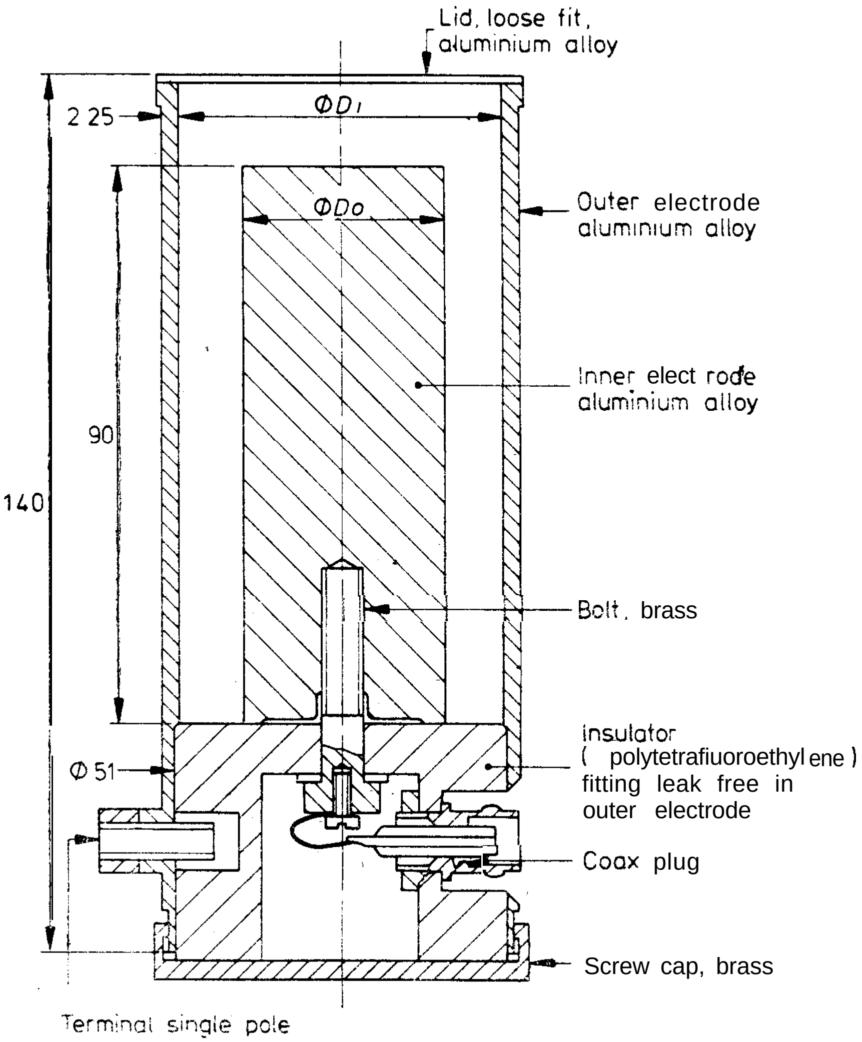
If the sample to be measured either has ionic material different from that in the previous test, or it is at a much lower concentration, rinse' the cell thoroughly five times with fresh toluene-acetone mixture and then once with treated n-heptane.

When the cell has been used for testing samples with high conductivities (more than, say, 1 000 pS/m), or when solutions, containing surface active materials have. been measured, cleaning the cell may be difficult. In such cases dismantle the cell and place all parts except the plug removed from the outer electrode in a Soxhlet apparatus containing boiling toluene-acetone mixture and leave it for several hours. Then rinse, all parts with treated n-heptane before assembly, and rinse the cell again after assembly.

If it is required to measure both low conductivities (less than 1 pS/m) and high conductivities (greater than 1 000 pS/m), it is advisable to keep one cell solely for the low conductivity samples.

After the cell has been cleaned, it should be checked by measuring the conductivity of the treated n-heptane, which should be less than 0·03 pS/m, repeat the cleaning procedure using the toluene-acetone and n-heptane solvents, and check again with treated n-heptane. If this fails, check the electrical leakage of the cell itself by carrying out the measurement procedure with the cell empty and dry. The result should be less than 0·01 pS/m; a typical result would be 0·002 pS/m. If the result is greater than 0·01 pS/m, clean the cell using the Soxhlet procedure described above.

c) *Sampling the liquid and loading the cell* — Clean all equipment using the same procedure as for the cell. To avoid loss of active components from the sample by transfer to the wall of the container, keep. the storage time in the container and the surface to volume ratio as small as possible. Avoid unnecessary pouring of the sample. from one container to. another.



All dimensions in millimetres; scale 1 : 1.

FIG. 4 MAIN FEATURES OF LIQUID CONDUCTIVITY CELL DESIGN

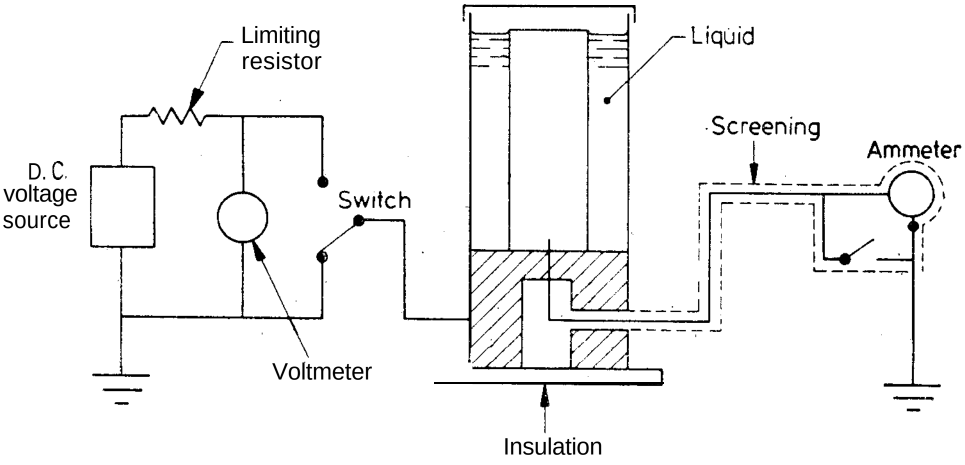


FIG. 5 ARRANGEMENT OF EQUIPMENT FOR MEASUREMENT

Flush the cleaned cell three times with the sample, empty it completely and then fill it. When using the cell of Fig. 4, load it with 100 ml of sample.

d) *Measurements* — Place the cell on a piece of insulating material with a resistance to earth greater than $10^7 \Omega$. With the switch turned to earth and the ammeter short-circuited, make the electrical connections to the cell. If the cell can be adjusted, set the voltage supply at 10 V (if using the cell of Fig. 4) and set the ammeter so that the voltage drop across its input resistance is less than 0·1 V.

Allow some time for any charge on the liquid to relax, if the conductivity is expected to be below 1 pS/m. The presence of this charge can be detected by switching the ammeter into the circuit. If the reading is small compared with that expected for the actual measurement, the influence of the charge can be neglected. After such a check short-circuit the ammeter again.

When relaxation is complete, turn the switch to the voltage supply and, after a fraction of a second, switch the ammeter into the circuit. Take the maximum current reading, which is normally reached within one or two seconds, and then turn the switch to earth and short-circuit the ammeter. Finally, measure the temperature of the sample with a clean thermometer.

The measurement procedure should be repeated with fresh cell fillings until a constant current reading is obtained.

16.1.3.4 *Calculation of result*

The conductivity of the sample at the measurement temperature is given by the equation:

$$\gamma = k \frac{I}{V} \times 10^{12}$$

where

y is the electrical conductivity (in pS/m);

k is the cell constant (in m-1). For the cell of Fig. 4, k = 1·00 m-1 ±1 percent;

I is the measured current (in A); and

V is the applied potential difference (in V).

16.2 The Volume Resistivity of a Powder

16.2.1 *Introduction*

This test is designed to measure the volume resistivity of powder in order to assess its ability to retain static electricity. For this purpose it is sufficient to know the order of magnitude of the resistivity. The equipment is suitable for measuring volume resistivities in the range $10^7 \Omega$ m to $10^{14} \Omega$ m.

16.2.2 *Summary of Method*

A sample of the powder is placed between two parallel electrodes and a high potential is applied to it. The resistance is derived by measuring the resultant current and the volume resistivity calculated from it using the dimensions of the electrode system.

16.2.3 *Apparatus*

The powder is 'placed in a resistivity cell; the essential details and typical dimensions of such a cell are shown in Fig 6. For powders with resistivities towards the lower end of the resistivity range, the resistance between the electrodes can be determined with a commercial instrument such as an insulationtester or a megohmmeter.

For higher resistivity powders the cell is included in a circuit such as that shown in Fig. 7, where the test potential is provided by a 500 V to 1 000 V dc source with an inbuilt current limiting resistor for safety purposes. The resultant current is measured by a dc ammeter with a range of 10^{-12} A to 10^{-4} A, depending on the resistivity of the powder involved. The earthed guard ring around the low voltage lead from the cell prevents any leakage current that might flow around the walls of the cell from reaching the electrometer, and this guard can be extended to screen the lead to the electrometer. In order to avoid the flow of a dangerously high current if, for example, the powder proved to be highly conductive, or the positive electrode were shorted to earth, a 1 M Ω resistor is put in series with the dc source.

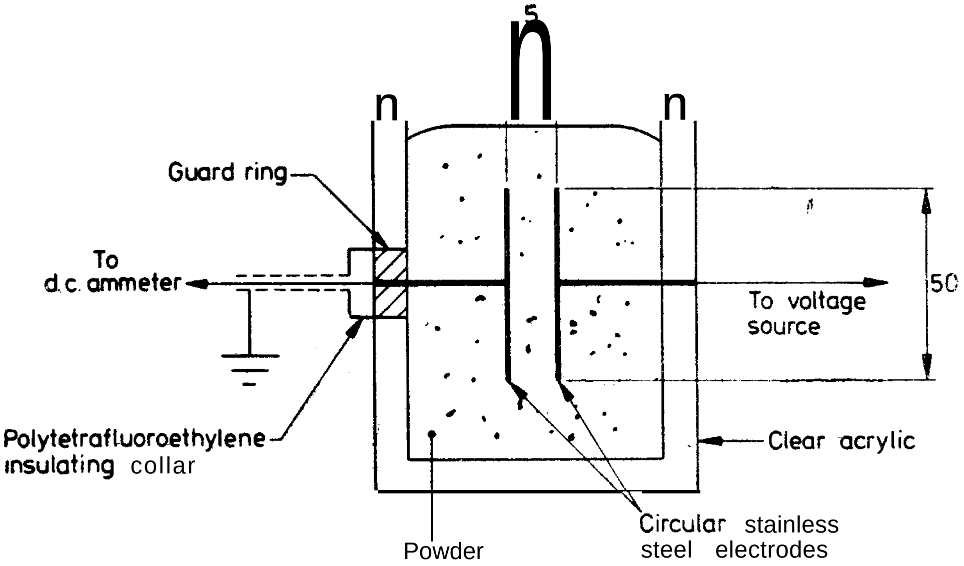
16.2.4 *Procedure*

a) *Preparation of the sample* — The measured resistance of the powder will depend upon the degree of compaction of the sample. Reproducible results are usually obtained if, after filling, the powder is tamped down by gently knocking the cell on the bench. Ideally, the compaction should be similar to that occurring in practice and, as an alternative to tamping, it may be possible to achieve this by pressing the powder with an appropriate weight.

b) *Measurements* — Comparative measurements should always be made at the same temperature and relative humidity, preferably those obtaining when the powder is in use.

In the electrometer circuit of Fig. 7, apply a potential between 500 V and 1 kV to the cell and allow sufficient time for initial polarization transients to decay before measuring the steady current. The precautions normal for high voltage equipment should be taken.

If a commercial instrument is used for measuring the resistance between the electrodes, the maker's instructions should be followed.



All dimensions in millimetres.

FIG. 6 MAIN FEATURES OF POWDER RESISTIVITY CELL DESIGN

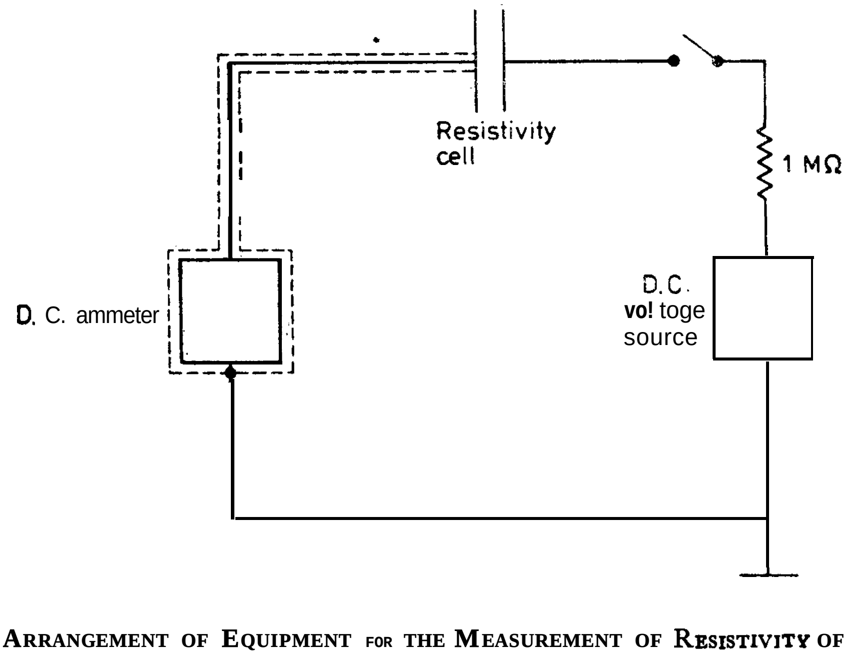


FIG. 7 ARRANGEMENT OF EQUIPMENT FOR THE MEASUREMENT OF RESISTIVITY OF POWDER

16.2.5 *Calculation of Result*

The volume resistivity of the powder is given by the equation:

$$\rho = R \frac{A}{l}$$

where

ρ is the volume resistivity (in Ω m),

R is the resistance of the powder (in Ω),

A is the area of each electrode (in m^2), and

l is the distance between the electrodes (in m).

Thus, for the dimensions given in Fig. 6:

$$\rho = 0{\cdot}393 \frac{V}{I} \Omega \text{ m}$$

This equation is adequate for deriving the order of magnitude of the resistivity. It assumes a uniform current density between the electrodes and no distortion of the current flow at the edges of the electrodes. The error due to edge effects could be reduced by adopting a guard ring format for the electrodes as in dielectric test cells.

16.3 Mass Charge Density of a Powder

16.3.1 *Introduction*

One means of assessing the electrostatic hazard due to powder in a powder handling plant is to measure the mass charge density of the powder. For this purpose an estimate of the order of magnitude of the charge density is adequate. The following simple test can be used at any point in the system where the powder can be diverted from the plant into a collector. A critical point is where the powder moves from the main units (for example, mills, pneumatic transfer lines) to air/powder disentrainment or storage units, for example, cyclones, filter bags, silos, etc).

16.3.2 *Summary of Method*

A quantity of charged powder is collected in an insulated metal container. The potential induced on the container is measured. The quantity of charge on the powder is equal to that repelled towards earth from the container, which is calculated from the measured potential and the capacitance of the container and measuring system. Alternatively, the current draining to earth from the container in a measured time is noted in order to obtain the quantity of charge. Division of the charge by the mass of powder yields the mass charge density.

16.3.3 *Apparatus*

The essential features of the apparatus are shown in Fig. 8. A conveniently sized metal container is insulated from earth and placed so as to collect powder issuing from the plant, Between the container and earth is connected either an electrostatic voltmeter or a current electrometer having an input impedance such that the leakage current is insignificant compared with the charging current; typical values are $10^{12}\,\Omega$ to $10^{14}\,\Omega$. This simple system is usually entirely adequate, but if the readings are unsteady or fluctuating, screening of the container and of the lead to the instrument may be helpful.

It should be remembered that if the voltmeter system is used the container constitutes an insulated conductor and appropriate precautions should be taken.

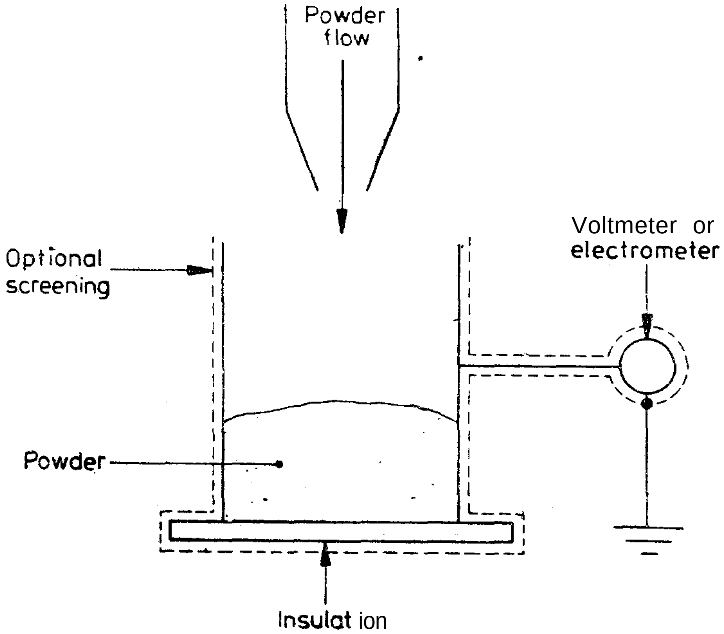


FIG. 8 ARRANGEMENT FOR THE MEASUREMENT OF MASS CHARGE DENSITY OF A POWDER

16.3.4 Procedure

Before the test is started, earth the container by connecting it momentarily to a convenient earthed point.

Allow the powder to flow into the container for a convenient period of time and measure either the final voltage or the current flowing to earth. Determine the mass of powder by weighing the container and its contents and subtracting the mass of the container.

If the voltmeter system is used, the capacitance of the container/measurement system is required. This can be measured by normal ac bridge methods.

16.3.5 *Calculation of Result*

a) *From voltage mesurement* — The mass charge density of the powder is given by the equation:

$$q = \frac{VC}{m} \times 10^{-6}$$

where

q is the mass charge density (in μ C/kg),

V is the measured potential I (in V),

C is the measured capacitance (in pF), and

m is the-mass of powder (in kg).

Also, the average rate of charge input to the container is given by the equation:

$$I = \frac{VC}{t} \times 10^{-12}$$

where

I is the rate of charge input (in A),

V is the measured potential (in V),

C is the measured capacitance (in pF), and

t is the time of flow (in s).

b) *From current measurement* — The mass charge density is given by the equation:

$$q = \frac{It}{m} \times 10^{6}$$

where the symbols have the same meanings as in the calculation in the voltage measurement case.

16.4 Measurement of Charge Density and Potential by Means of An Electrostatic Field Meter

16.4.1 *Introduction*

Methods of investigating the distribution of electrostatic charges or potentials usually rely upon the detection and measurement of the associated electrostatic fields. Many commercial field meters are available for such measurements. 16.4.2 and 16.4.3 consider the types of meters and give some examples of their use for the assessment of electrostatic hazards.

16.4.2 *Apparatus*

In most modern field meters, an insulated metal plate is used as a field-sensing probe. The potential induced on this plate is measured and this indicates the strength of the electric field.

In practice, the induced potential is low and, relative to the charges in its vicinity, the plate behaves essentially as an earthed conductor.

In the simplest form of meter, a dc system is used to measure the potential, and care is required to maintain a very high degree of insulation (greater than, say, $10^{12}\,\Omega$) of the probe from earth, and to prevent drift in the instrument zero due to the collection of charge on the probe. Frequently, the 'field mill' principle is used, in which a rotor alternately exposes and shields the probe, so that an ac signal is generated. This reduces the problems of insulation and zero drift. Instruments based on radio-activity are also available, but, these are used more for qualitative than for quantitative tests.

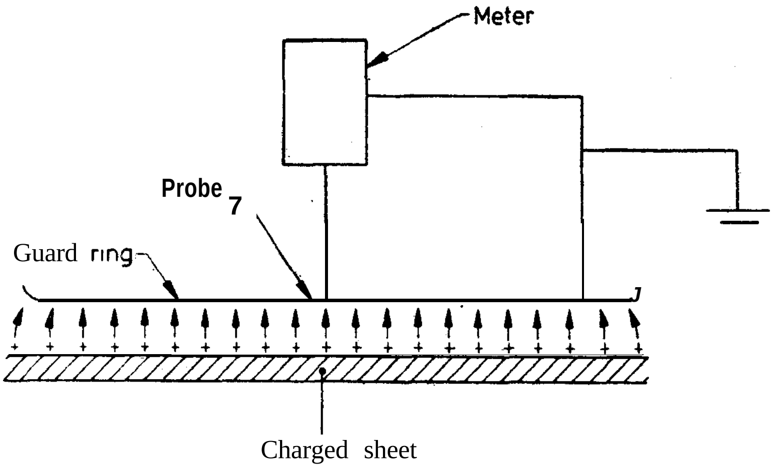


FIG. 9 ARRANGEMENT FOR MEASUREMENT OF SURFACE CHARGE DENSITY ON A HIGH RESISTIVITY NON-CONDUCTING SHEET

16.4.3 Procedure

16.4.3.1 General

Quantitative interpretation of field measurements has to take account of the geometrical arrangement of the field meter, the charged object or objects and any nearby conductors. The reading of a calibrated meter gives the average field strength over the area of the probe, but care is needed in its interpretation. The field may have been badly distorted by the presence of the probe, or it may be part of a highly non-uniform field distribution. Examples of the use of field meters are given in 16.4.3.2 to 16.4.3.4.

16.4.3.2 ***Qualitative use***

Any field meter can be used qualitatively in the diagnosis of electrostatic problems, for example, to locate a centre of high charge density, or to check on the efficiency of a static eliminator. It is useful to bear in mind two significant field strength levels:

3×10^3 kV/m :	the breakdown strength of air in large gaps, which sets an upper limit to the fields observable in air.
10 kV/m :	electrostatic forces generally have no appreciable effect unless the field exceeds this level.

16.4.3.3 ***Measurement of surface charge density on high resistivity sheet materials***

In this application it is important to surround the probe with a guard ring to define the area under examination. Figure 9 shows the basic arrangement of equipment for measurements on an isolated sheet carrying a uniform distribution of charge.

The guard diameter should be at least 10 times greater than that of the active area of the probe. The probe/guard assembly is held parallel to the surface of the sheet in a region well away from metal objects such as rollers and brackets. With this arrangement:

$$\sigma = \varepsilon_0 K$$

where

a is the surface charge density (in C/m^2),

K is the measured field strength (in V/m), and

ε_0 is the permittivity of free space ($8{\cdot}85 \times 10^{-12}$ F/m).

The result is virtually independent of the distance from the probe to the surface, but anomalous readings may be obtained with a non-uniform charge distribution, unless the probe to surface distance is small compared with the diameter of the active part of the probe.

Figure 10 gives a chart of the relationship between a and K with an indication of the phenomena to be expected at various levels. It applies only in the absence of conductors which would attract a proportion of the field due to the charge on the sheet.

The charge density obtained with the arrangement of Fig. 9 is the algebraic sum of the densities of all charges present, whether they are on the upper or lower surface of the sheet or trapped within it. If charge is present on both surfaces, but not within the volume of the sheet, that on the upper one can be measured with the arrangement in Fig. 11, where the lower surface is in contact with an earthed metal plate. The same method is applicable to a coating on metal with a charge on its outer surface.

In the arrangement of Fig. 11, the charge density on the upper surface is given by:

$$\sigma = \frac{a + b/\varepsilon}{b/\varepsilon} \varepsilon_0 K$$

where

a is the surface charge density (in C/m^2),

K is the measured field strength (in V/m),

ε_0 is the permittivity of free space ($8{\cdot}85 \times 10^{-12}$ F/m),

a is the thickness of the sheet (in m),

b is the distance between the probe and the surface (in m), and

ε is the relative permittivity of the material of the sheet.

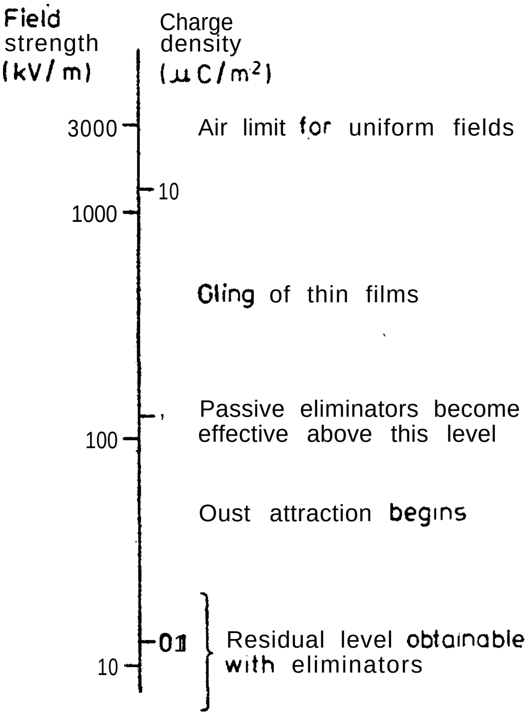


FIG. 10 GUIDE TO FIELD STRENGTH/SURFACE CHARGE DENSITY RELATIONSHIP FOR HIGH RESISTIVITY SHEETS

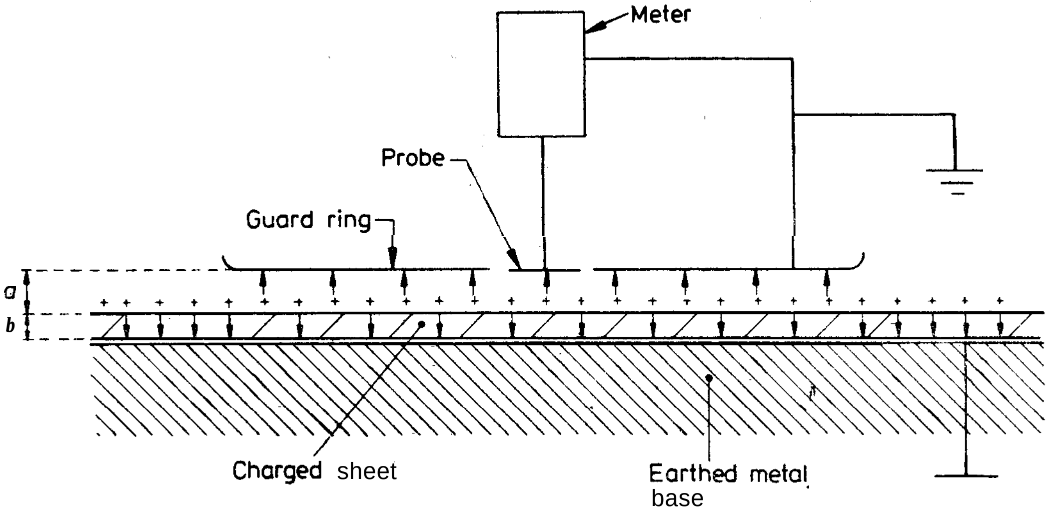


FIG. 11 ARRANGEMENT FOR THE MEASUREMENT OF THE SURFACE CHARGE DENSITY ON A SHEET WITH CHARGES ON BOTH SIDES

16.4.3.4 *Measurement of potentials*

If the field pattern associated with a system of charges is known, an observation of the field strength at one place can be used, in principle, to derive surface and space potentials in the system. In some cases, the field pattern can be obtained by mathematical modelling, or a correlation between field and potential values may be established experimentally. The procedures are complicated and each situation requires individual treatment. Two important cases are mentioned briefly in (aj and (b) below:

a) *Liquid surface potential* — A measurement of the vertical field strength is made by means of a field meter suspended at a known distance above the surface of the charged liquid. To a first approximation, it can be assumed that the field between the surface and the probe is uniform. The potential of the surface is then given by:

$$V = Kx$$

where

V is the surface potential (in V),

K is the measured field strength (in V/m), and

x is the distance between the probe and the surface (in m).

When quoting a potential derived in this way, an estimate should also be given of the uniformity of the field.

It should be remembered that the introduction of the field meter may trigger sparking, and appropriate precautions should be taken if there is any possibility of a flammable mixture.

b) *Space charge potential* — For a large vessel containing a uniform distribution of charge throughout its volume, experimental and theoretical studies have shown that a field meter introduced into the volume on the end of an earthed metal tube gives a reading which is proportional to the potential which would exist at the probe position if the field meter and tube were absent altogether. For a tube of diameter about 100 mm, the potential is given by:

$$V = kK$$

where

V is the potential (in V),

k is a constant with a value 0·12 m, and

K is the measured field strength (in V/m).

Potentials at other points may then be computed assuming "a uniform charge distribution. An alternative approach is to set the field meter probe in the wall of the vessel.

Precautions should be taken where flammable mixtures may be involved.

16.5 Minimum Ignition **Energy**

16.5.1 *Introduction*

The purpose of the test is to obtain information on minimum ignition energy which can be used to assess the ignition risk due to static electricity discharges. Test techniques are available for both flammable gases and dusts. The minimum ignition energies of gases are comparatively low and in the following ranges:

gas/oxygen mixtures : 0·002 mJ to 0·1 mJ
gas/air mixtures : 0·01 mJ to 1·0 mJ

Since these levels are below 'the energies frequently available in electrostatic discharges, it is normal to assume that flammable gases present an electrostatic hazard, and there is then no need to measure their minimum ignition energies. If, in a particular application, an accurately measured value is needed, suitable techniques are described by Lewis and von Elbe*.

In contrast to gases, the minimum ignition energies of powders can be very large, covering a range from less than 2 mJ up to 5 000 m J or more, and measured values are required for hazard assessments. The procedure described is, therefore, that applicable to powders.

NOTE — This test is intended for use with the normal range of flammable powders and should not be used for highly reactive materials or detonating deflagrating explosives.

16.5.2 *Summary of Method*

The type of discharge in the majority of electrostatic ignitions is a spark from an insulated conductor. In the test method, sparks are produced by the discharge of a capacitor and, since virtually all the stored energy on the capacitor appears in the spark, the energy released is given by $\frac{1}{2}CV^2$, where C is the capacitance in the circuit and V is the potential at the moment of discharge.

Sparks of various energies are produced in suspensions of the dust under test, and the occurrence of ignitions is recorded; a range of dust concentrations is explored to cover the most readily ignitable mixture in air.

Consistent results may not be achieved until experience of the method has been gained, owing to the difficulty of making adequate dust dispersions. As a check that reasonable results are being obtained tests should be made using anthroquinone powder passing a 200-mesh sieve; its minimum ignition energy should be less than 10 mJ.

16.5.3 *Apparatus*

A diagram of the apparatus is shown in Fig. 12. Powder in the dispersion cup is dispersed by a blast of air injected through the pipe at the base and directed downwards by the conical deflector over the end of the pipe. The air is released by a solenoid valve from an air reservoir having a volume of about 50 ml, where it is held at a pressure between 8 kPa and 10 kPa. Sparks pass between the hemispherical metal electrodes; the electrode separation can be varied but should be not less than 2 mm.

The sparks are produced by the electrical circuit shown in Fig. 13. The high voltage dc supply slowly raises the potential of the capacitor until a spark occurs, and the cycle is then repeated, giving a series of sparks, each of the same energy. A current-limiting resistor with a value between $10^8\Omega$ and $10^9\Omega$ is included in the circuit. The potential across the capacitor is measured by an electrostatic voltmeter with a decoupling resistor in series having value between $10^8\Omega$ and $10^9\Omega$.

16.5.4 *Procedure*

a) *Preparation of the sample* — The sensitivity of the powder to ignition depends not only on its chemical composition but also on its physical form and water content.

The sample for test should have a particle size distribution representative of the finest cloud that can be formed with a flammable concentration. With few exceptions, the sample should be sieved so that all particles have a size less than 75 µm (passing a 200-mesh sieve). The water content of the powder should be the minimum encountered during the normal processing and use of the powder.

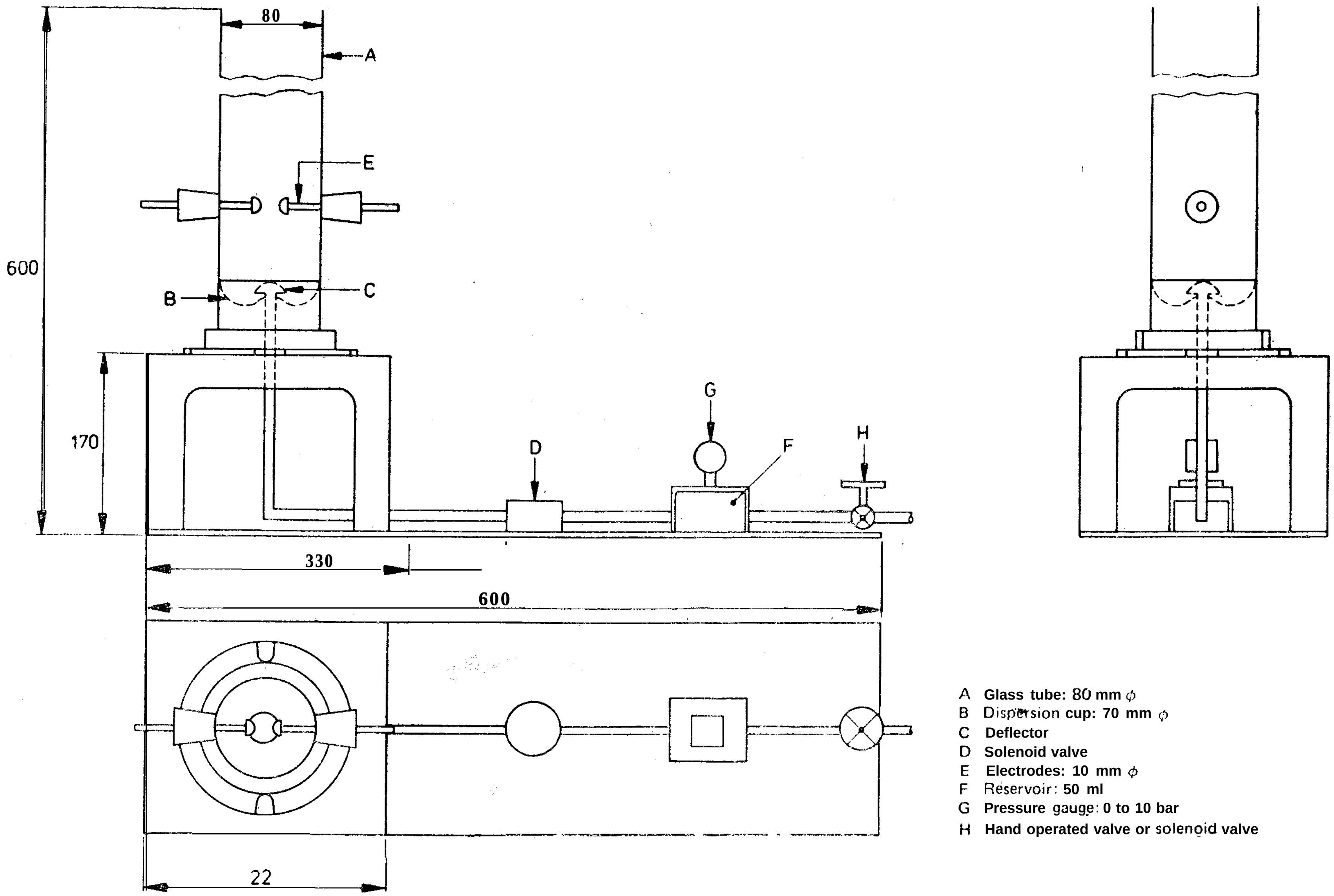
b) *Measurements* — The general procedure is to make tests with sparks at standard energy levels; those recommended are 500 mJ, 25 mJ, 10 mJ and 1 mJ. If a more precise measure of the minimum ignition energy is needed, tests can be made at intermediate energy levels.

The settings for sparks of the required energy are determined before any powder is placed in the ignition chamber. After choosing a capacitor of appropriate value, select a voltage in the range 10 kV to 30 kV and then adjust voltage and electrode separation by trial until sparks of the required energy, given by $\frac{1}{2}CV^2$, occur at the maximum possible electrode spacing (not less than 2 mm). In this expression, V is the-voltage at which the spark occurs and C is the total capacitance at the high voltage electrode, which can be measured by normal ac bridge methods.

To make an ignition test, earth the high voltage electrode and load a quantity of prepared powder of the order of 0·5 g to 1·0 g into the dispersion cup. Then switch the dc voltage supply into the circuit and as sparks start to pass between the electrodes disperse the powder by operating the solenoid valve. Note whether ignition occurs and. flame propagates away from the spark gap.

The first test should be at a spark energy of 500 mJ. If there is an ignition, reduce the ignition energy to 100 mJ, and continue in this way down the energy range until ignition does not occur.

***Static Electrification; Institute of Physics Conference; Serial No 11, p : 158, 1971.**



A Glass tube: 80 mm ϕ
B Dispersion cup: 70 mm ϕ
C Deflector
D Solenoid valve
E Electrodes: 10 mm ϕ
F Reservoir: 50 ml
G Pressure gauge: 0 to 10 bar
H Hand operated valve or solenoid valve

All dimensions in millimetres.

FIG. 12 APPARATUS FOR THE DETERMINATION OF MINIMUM IGNITION ENERGIES OF DUSTS

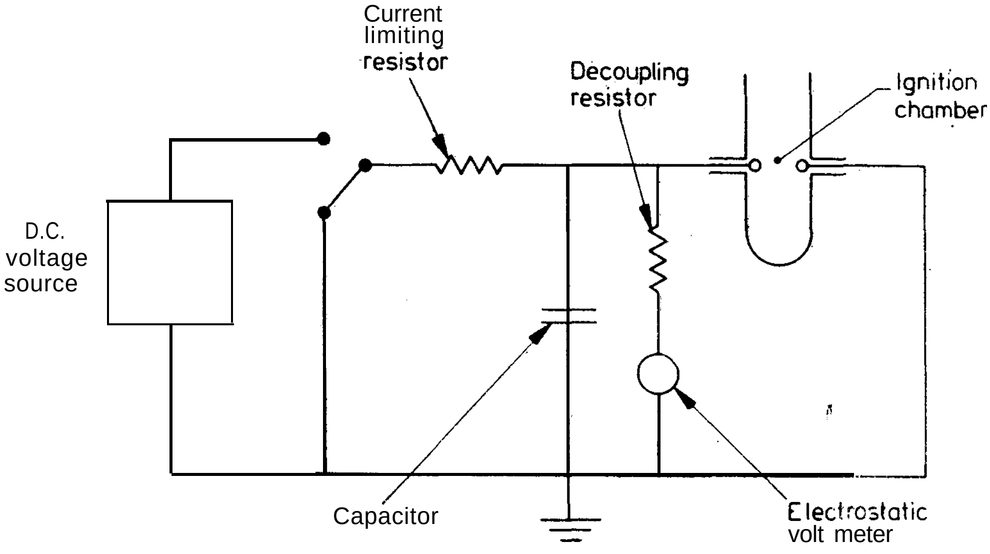


FIG. 13 ARRANGEMENT FOR PRODUCTION OF SPARKS OF KNOWN ENERGY

If, at any energy level, there is no ignition, the test should be repeated ten times. If there has still been no ignition, further tests should be made varying the quantity of powder, before concluding that ignition does not occur at the spark energy in question.

The precautions normal for the use of high voltage equipment should be taken throughout the test procedure, and the operator should be protected from the dust ignition.

16.5.5 *Interpretation of Results*

A chart is given in Fig. 14 to provide guidance on the precautions which would be appropriate with powder suspensions in air. It should be supplemented by reference to the appropriate clauses of this code.

16.6 Resistance to Earth from Metallic and Non-metallic Objects

16.6.1 *Introduction*

In many installations, particularly those containing non-conductors, there is a need to check that the various parts of the system are adequately earthed, For this purpose, instrumentation is required to measure resistances in the range $10^5 \Omega$ up to say $10^9 \Omega$, between earth and metal components which may be partially insulated from earth, and between earth and any part of the surface of an object made of non-conducting material.

16.6.2 Summary *of Method*

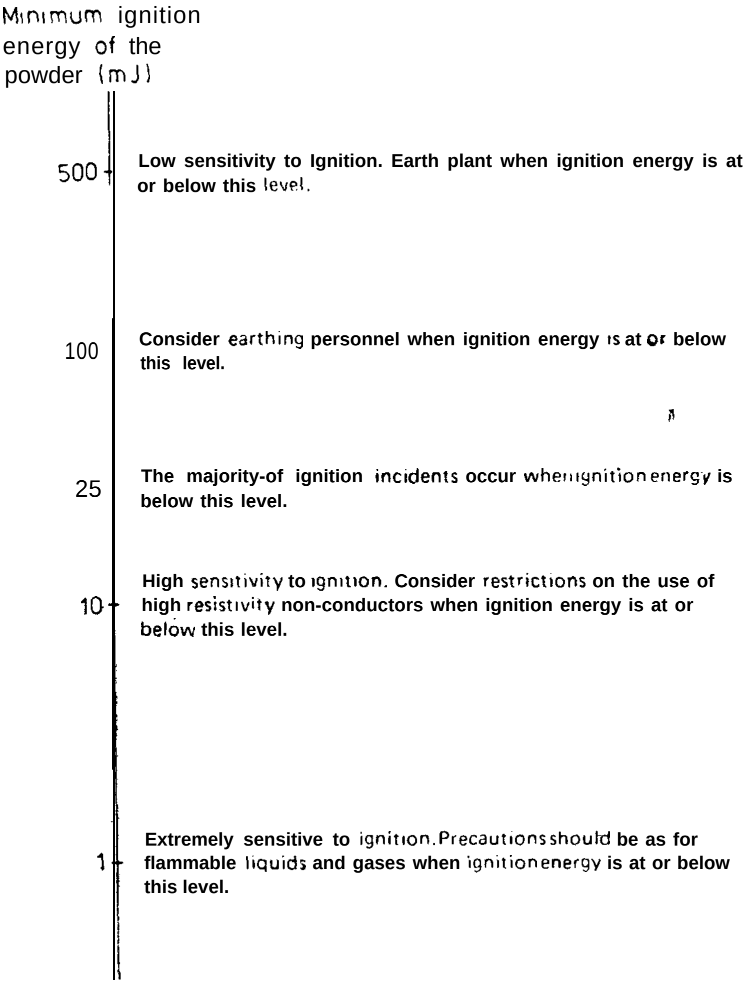
A direct voltage is applied between earth and the object under test and the ensuing current to earth is measured. Some non-conductors do not obey Ohm's law, so that the measured resistance to earth depends on the applied voltage. A value of about 500 V is taken as standard in this method, although a lower voltage may he used in some circumstances (see 16.6.3).

16.6.3 *Apparatus*

For resistances up to 10s Ω, measurements should preferably be made using a proprietary insulation tester or megohmmeter having a nominal open-circuit voltage of 500 V dc.

Alternatively, and for higher resistances, a circuit such as that shown in Fig. 15 may be used. The voltage source is a battery or a rectified power source, and a current limiting resistor, Y, is included. Its value should be such that when the maximum permissible resistance to earth, *R,* is being measured, the potential applied to the object under test is not less than 400 V, that is, *r* should be above R/4.

The voltmeter should have a range of 0 V to 500 **V,** and the range of the ammeter depends on the resistance being measured (for example, 0 to 10^{-6} A for $10^9 \Omega$). With suitable switching, a single multifunctional meter may be used. Measurements using the above instrumentation may produce incendive sparks and tests should not, therefore, be made in flammable atmospheres. If tests are required under these conditions, specialized equipment and techniques should be used. The use of low voltage equipment is acceptable if a maximum limit on resistance only is being sought; because of possible deviations from Ohm's law it may give an abnormally high result and hence cause a satisfactory piece of equipment to fail the test.



500 — Low sensitivity to ignition. Earth plant when ignition energy is at or below this level.

100 — Consider earthing personnel when ignition energy is at or below this level.

25 — The majority-of ignition incidents occur when ignition energy is below this level.

10 — High sensitivity to ignition. Consider restrictions on the use of high resistivity non-conductors when ignition energy is at or below this level.

1 — Extremely sensitive to ignition. Precautions should be as for flammable liquids and gases when ignition energy is at or below this level.

NOTE — This guide should not be applied to the special case of high resistivity powders in large non-conducting containers (*see* **11.3.3**).

FIG. 14 GUIDE TO ELECTROSTATIC PRECAUTIONS FOR POWDER SUSPENSIONS IN AIR

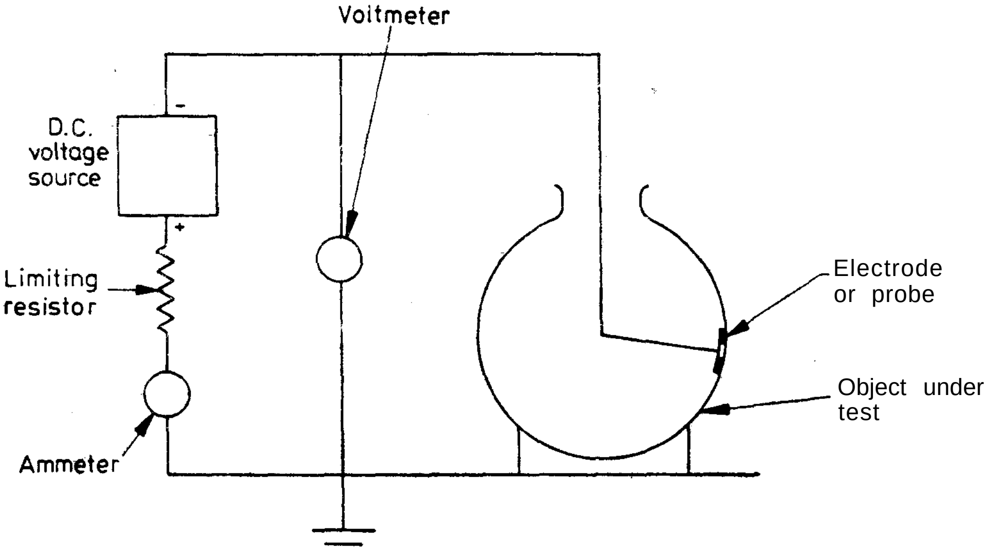


FIG. 15 MEASUREMENT OF RESISTANCE TO EARTH

The earth connection should be a buried electrode, a water pipe or part of the metallic structure of a building. It is important to ensure that the lead to the object under test is adequately insulated from the operator and from any earthed readings before contact is made with the surface.

16.6.4 *Procedure*

a) *Electrical contact with the object* — If the object is metallic, a simple metal to metal contact presents no difficulty.

If the object is made of non-conducting material, such as a polymer treated to have some degree of conductivity, precautions may be required to ensure satisfactory electrical contact. The contact should then be made by means of an electrode consisting of a metal disc of 50 mm diameter conforming in shape to the surface being tested. The surface beneath the electrode should be coated with a conductive medium. Suitable media are a conductive silver lacquer, aqueous colloidal graphite, which may be allowed to dry, or a conductive liquid such as the following:

	Parts by mass
Anhydrous polyethylene glycol, (molar mass 600)	800
Water	200
Wetting agent (detergent)	1
Potassium chloride	10

In the absence of a conductive medium a high result can be expected, but provided that this falls below the permissible maximum resistance, and no minimum is specified, direct contact between the surface and electrode is acceptable.

In some tanks constructed of polymeric materials, a partially conductive inner layer is protected from contact with the liquid contents by a thin non-conductive gel coat. To measure the resistance to earth of the conductive layer, a sharp-pointed electrode may be used to penetrate the gel coat and make contact with the underlying layer.

b) *Measurements* — The measurement is made by contacting the object under test with a suitable lead or electrode and observing the current on the ammeter. Before the test is carried out the object should be allowed to reach equilibrium with its surroundings and both the temperature and the relative humidity should be recorded at the time of the measurement.

16.6.5 *Calculation of Result* — The resistance to earth is given by:

$$R = \frac{V}{I}$$

where

R is the resistance (in Ω),
V is the applied potential (in V), and
I is the measured current (in A).

16.7 Personnel Resistance Monitor

16.7.1 *Introduction*

The manufacture of a shoe sole material to have the desired degree of conductivity after moulding, and the addition of inner soles and liners, is difficult to control. The conductivity of the finished product can, subsequently, be affected in use by exposure to certain chemicals or physical conditions. There is therefore, a need to measure, under normal conditions of use, the total resistance between a person and earth through his footwear, to check that it is appropriate to the circumstances.

16.7.2 *Summary of Method*

A small constant current is arranged to flow through the person from his hand through his footwear to an earthed metal plate on which he stands. A voltmeter displays a reading proportional to the potential drop across the person and is calibrated to give the required resistance directly.

16.7.3 *Apparatus*

In order to make the measurement, current is passed through the person from a conducting handle which he grasps to an earth plate on which he stands. This imposes limits on the voltage and current that can be used, or which could arise under fault conditions.

A monitoring instrument can be designed either to give a meter indication of the resistance or conductance, a 'go/no go' signal at a specified limit value, or both. A high level of insulation is required, particularly at the operating handle, to avoid faulty low readings by partial short-circuiting. The operating handle and its associated switches should be of robust construction.

Equipment of this type is available commercially. The basic circuit of a highly stabilized monitor suitable for a permanent installation is shown in Fig, 16. The meter gives a linear indication from zero to 2 × 10s Ω with an accuracy of ± 2 percent of full scale deflection (FSD). Amplifiers Al and A2 form a current generator producing, through R2, R3 and R4, a current which is constant and proportional to V ref/$R2$. Adjustment of this current is provided by the 'Span' preset. The 'Balance' preset trims the circuit and ensures that changes in input resistance do not affect the constant current. Additional optional circuitry is included to provide 'Red' (dangerous) and 'Green' (safe) indicator lamps; the operating point for these lamps can be set to any value in the range.

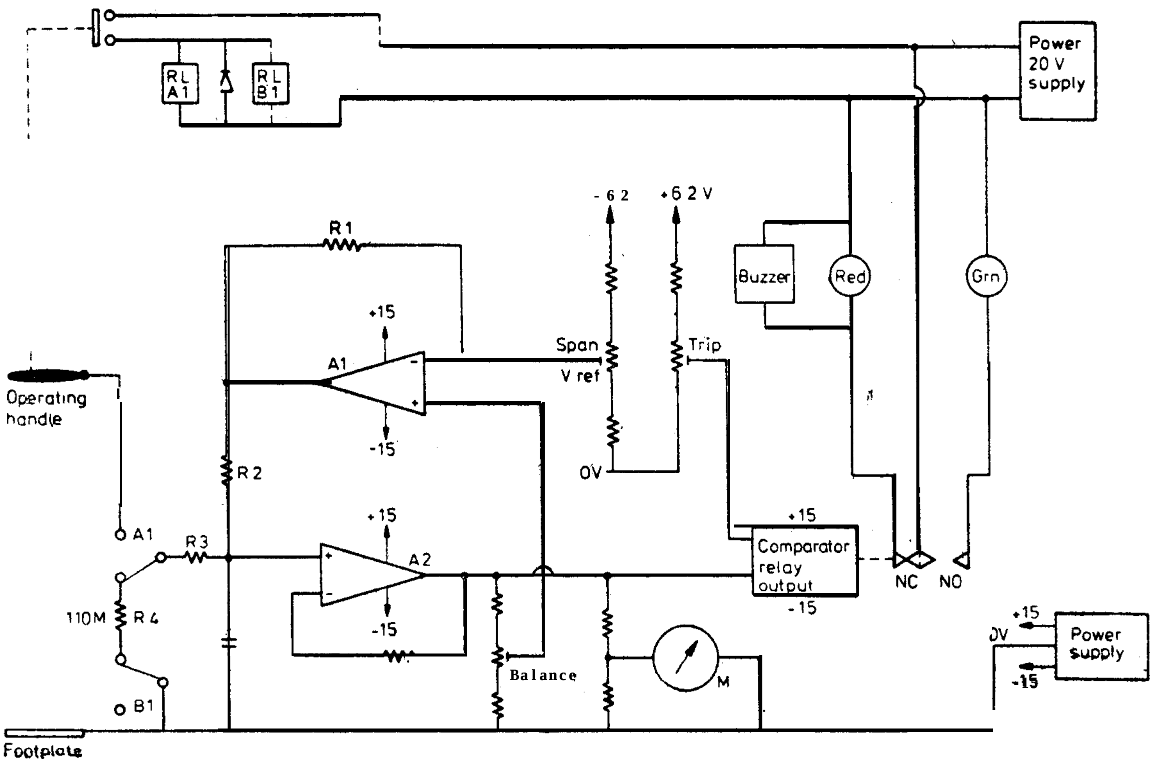


FIG. 16 TYPICAL BASIC CIRCUIT FOR PERSONNEL RESISTANCE MONITOR

To make a measurement, the person is put in place of *R*4 through operation of the relay *RL* Al and his resistance to earth is displayed directly on the meter *M*.

Since the equipment is mains operated, it should be sited outside hazardous areas.

16.7.4 *Procedure*

The person under test stands on the foot plate, grasps the operating handle and depresses it to close the test circuits. His resistance is shown on the meter, and if it exceeds the preset limit, the 'Red' (dangerous) lamp is illuminated and a buzzer sounds.

16.7.5 *Interpretation of Result*

Two classes of soling material which will dissipate static electricity are recommended.

a) antistatic footwear having a resistance between 5 x $10^4\,\Omega$ and 5 x $10^7\,\Omega$.

b) conducting footwear having a resistance less than 1·5 x 105 Ω.

Testing of these properties are under consideration. The voltage specified for use in these tests is not less than 200 V, which is much higher than can be permitted in a personnel tester. Some rubbers give results dependent on the test voltage.

Under practical conditions, realistic values for personnel resistance determined by means of a monitor are:

antistatic: 1 x $10^5\,\Omega$ to 1 x 10s Ω.

conducting: less than 1 x $10^5\,\Omega$.

16.8 The Surface Resistivity of a Textile Fabric

16.8.1 *Introduction*

The ability of textile fabrics, used for clothing, domestic or industrial purposes, to dissipate static electricity depends upon their surface resistivities. In such woven or knitted materials, the surface resistivity usually varies with the direction of current flow in the specimen, and a mean value is conveniently obtained by using concentric electrode geometry.

The test is intended for fabrics with moderate or low surface resistivities, less than, say, $10^{13}\,\Omega$. It is applicable mainly to homogeneous fabrics, new fabric blends, coated apparel fabrics in which the coating is less resistive than the substrate, and is worn outermost, and fabrics containing small quantities of conducting fibres. In the last case, the maximum measured resistivity is used, and not typically low values (less than $10^5\,\Omega$) due to conductive fibres bridging the electrodes.

16.8.2 *Summary of Method*

An electrode assembly is placed on a sample of the fabric and the resistance between the electrodes is measured. The average surface resistivity is derived from the resistance using the dimensions of the electrode system. Owing to the dependence of the electrostatic properties of most fabrics upon humidity and temperature, these variables are controlled.

16.83 *Apparatus*

The electrodes comprise a central cylindrical and an outer annular electrode arranged concentrically. Suitable electrodes are available commercially having the dimensions shown in Fig. 17; they are of solid brass and the space between them is filled with a high resistivity plastics. Incorporated in this plastics annulus is a brass guard ring, and both plastics and guard ring are recessed so that they do not contact the fabric surface. Concentric electrodes of other dimensions may be used.

The fabric under test is placed on a sheet of high resistivity plastics which, for the electrodes of Fig. 17, should have dimensions not less than 250 mm × 250 mm × 10 mm. This in turn is on an earthed metal plate. The electrode assembly rests on the fabric as shown in Fig 17.

A direct measure of the resistance across the annular area of fabric between the electrodes can be obtained by means of a megohmmeter with an applied voltage of 500 V. Alternatively, a potential of 500 V can be supplied from a dc source with an inbuilt safety resistor, and the current measured with an electrometer of input impedance of not less than $10^{14}\,\Omega$.

16.8.4 *Procedure*

16.8.4.1 Sample conditioning

Fabric pieces of sufficient size to obtain three independent values of surface resistivity, preferably not less than 1 m^2 in area, are recommended. They should be conditioned and tested at a relative humidity and temperature appropriate to the conditions in which they are to be used. For monitoring purposes 65 ± 2 percent RH at 27 ± 2°C is widely used in the textile industry, but 40 ± 2 percent RH at 27 ± 2°C is more relevant to conditions in practice. The conditioning time prior to measurement should be not less than 16 hours.

Tests on full garments which are not to be destroyed should be made on the outer fabric of the garment only.

New fabrics and garments may have finishes on them which reduce the resistivity of the material and which are usually removed during washing or dry cleaning. In some cases it may, therefore, be appropriate to wash or dry clean the material before doing the tests.

16.8.4.2 *Measurement*

Wipe clean the lower surfaces of the electrodes and the upper surface of the plastics base plate with a paper tissue damped with isopropyl alcohol. Place the fabric on the plastics base plate and rest the electrode assembly on it. If a megohmmeter is being used, measure directly the resistance between the electrodes. When using an electrometer, make the connections as shown in Fig. 17; the reading changes with time after applying the voltage, and it is recommended that a period of 15 seconds should be allowed to elapse before taking a reading.

Repeat this measurement procedure twice at other parts of the fabric.

With lined clothing, the plastics base plate and earthed metal plate are inserted between the lining and the outer fabric so that only the latter is between the electrodes and the base plate.

16.8.5 *Calculation of Results*

From each of the three values of resistance, the surface resistivity is calculated using the following equation, and the mean value is determined:

$$s = \frac{2\pi}{\log_e (r_2/r_1)} R$$

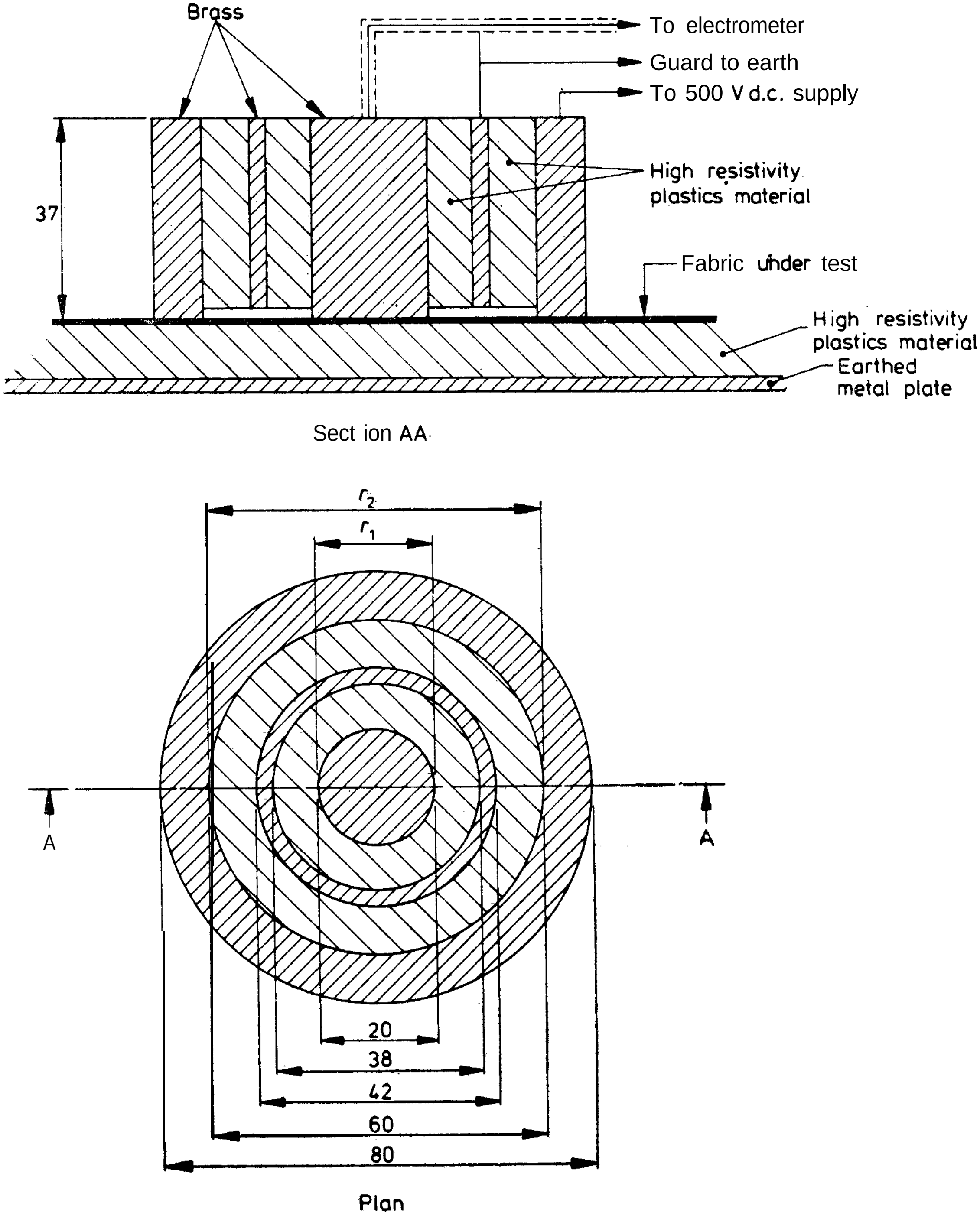
where

s is the surface resistivity (in Ω),

R is the measured resistance (in Ω),

r_1 is the radius of the inner electrode (in mm), and

r_2 is the inner radius of the outer electrode (in mm).



All dimensions in millimetres.

FIG. 17 ELECTRODE SYSTEM FOR SURFACE RESISTIVITY OF TEXTILE FABRICS

SECTION 5 RECOMMENDATIONS FOR PARTICULAR INDUSTRIAL LOCATIONS

17 FIXED METAL TANKS FOR THE STORAGE OF LIQUIDS

17.1 General

Static electricity hazards can arise in various operations connected with fixed storage tanks for liquids, including filling, gauging and sampling. Charge on the liquid may be generated within the tanks due to splashing or free fall, and/or, in the pipeline system feeding the tank. Charging may also be associated with personnel undertaking tasks on the tank, such as gauging or sampling, and with cleaning oparations.

An ignition hazard is created when charge is retained in the liquid, on insulated conductors or on personnel in the presence of a flammable vapour/air mixture, mist or foam. To avoid these hazards the recommendations given in **17.2** to **17.8 should** be followed.

17.2 Earthing

17.2.1 The tank and its associated pipework and fittings should all be in good electrical contact with each other and with earth, so that the resistance to earth is at all points less than 10 **Ω.** Electrical continuity checks should be made before the equipment is brought into use, and subsequently where maintenance or modification could affect electrical continuity (see 15).

17.2.2 New tanks or tanks that have been out of service for repairs, should be inspected prior to the initial fill for any potential floating objects, such as cans, that could form insulated conductors. Such objects should be removed.

17.2.3 It should be ensured that personnel working on the tanks do not present an ignition risk (see 43.3.1).

17.3 Tank Filling

17.3.1 Splash filling into a tank where a flammable atmosphere may exist should be avoided, in order to prevent the formation of a charged mist. This can be achieved either by bottom entry or by the use of a fill pipe reaching to the bottom of the tank without actually touching it.

17.3.2 For liquids with conductivity up to and including 50 pS/m the inlet should be designed to minimize turbulence and the agitation of any heavier immiscible liquid or sediment on the tank bottom.

17.3.3 Entrained air or other gas should be avoid-- ed in liquids with conductivities up to and including 50 pS/m if there is any possibility of immiscible liquid or sediment on the tank bottom.

17.3.4 For liquids with conductivity up to and including 50 pS/m, the linear flow velocny in the pipe entering the tank should not exceed 1 m/s until the inlet has been covered and should be maintained at 1 m/s if a second immiscible phase is present; an example is water suspended in oil. A precise value for the safe maximum linear velocity in the absence of a second phase in large tanks has not been established. However, experience indicates that the limitations on flow rates. imposed by the present designs of pipeline systems have been adequate to maintain safe operations. There is no evidence that flow velocities up to and including 7 m/s are hazardous. For storage tanks of the order of size of road/rail tanks the safe maximum linear velocity should be calculated by the procedure given in 21.3.3.

17.3.5 For liquids with conductivity greater than 50 pS/m the requirements of **17.3.2**, **17.3.3** and 17.3.4 can be disregarded. An antistatic additive may be used to raise the conductivity of a. low conductivity liquid above 50 pS/m, provided that it is compatible with the intended use,of the liquid.

17.4 Filters

Fine particle filters installed in the pipeline system upstream of the tank can produce a significant amount of charge. It is recommended that the methods for dealing with the charge given in **30** are followed.

17.5 Gauging and Sampling

The introduction into a tank of equipment for gauging and sampling may produce additional static electricity hazards. It is recommended that the procedures given in 20 are followed.

17.6 Tank Cleaning

Tank cleaning operations may give rise to static electricity hazards. It is recommended that the procedures given in 28 are followed.

17.7 Floating Roof Tanks

When a liquid with conductivity up to and including 50 pS/m is pumped into a metal tank with a floating roof, precautions for earthing (see 17.2), filling (*see* 17.3), fine particle filters (see 17.4) and gauging and sampling (see 20) are applicable until the floating roof is buoyant. Thereafter, only the earthing, gauging and sampling precautions are necessary.

17.8 Floating Blankets

17.8.1 Floating blankets in tanks used for storing liquids with conductivities up to and including 50 pS/m should be fabricated from metal, from non-conducting material entirely coated with antistatic material or from antistatic material. The blanket should be adequately earthed. Tanks with such blankets should be treated as if the blanket were a floating roof (see 17.7).

17.8.2 Conducting floating spheres of balls intended to suppress evaporation loss should not be used with liquids having a conductivity up to and including 50 pS/m. Non-conducting spheres should not be used with liquid at any conductivity level if there is any possibility of the presence of a flammable atmosphere.

18 FIXED NON-METALLIC TANKS FOR THE STORAGE OF LIQUIDS SITED PARTIALLY OR WHOLLY ABOVE GROUND

18.1 General

The charging processes and static electricity hazards associated with fixed metal storage tanks (see 17.1) are also encountered with non-metallic tanks. If tanks are made from high resistivity materials charge may also be generated and retained on the materials itself by the liquid handling operation or by internal or external rubbing. This presents additional hazards, especially if there are insulated metal components, such as bolts, flanges and valves, or if the surface is contaminated with isolated areas of conductive material, such as water or grease.

As in metal tanks, an ignition hazard is created when charge is retained on the liquid, on insulated conductors or on personnel in the presence of a flammable vapour/air mixture, mist or foam. The risk of an internal discharge from the liquid surface, for example, during gauging, is enhanced with tanks of high resistivity material because the dissipation of charge from the liquid is impeded and because the distribution of the field within the tank results in a greater field strength at the surface than in a metal tank, In addition, there is increased risk outside the tank if it is situated in a hazardous area, owing to the possibility of charge on the tank itself, even when a non-flammable liquid is being handled.

Recommendations for avoiding electrostatic hazards are given in 18.2, 18.3 and 18.4. They should be considered in conjunction with measures to deal with risks from other sources, for example, the general fire risk associated with the storage of large quantities of flammable liquids in non-metallic containers and mechanical strength limitations on larger containers.

18.2 Tanks Made of High Resistivity Materials

The use of large storage tanks completely fabricated from high resistivity materials, such as synthetic polymers and glass reinforced plastics having a volume resistivity greater than $10^8\,\Omega m$ and/or a surface resistivity greater than $10^{10}\,\Omega$ is not recommended. The exception is when it can be shown that the liquid handling operations do not produce dangerous levels of static electricity and that no charge generating processes exist outside the tank.

Specialist advice should be sought before installing tanks of high resistivity materials.

If such a tank is installed, rubbing of its surface, for example, in cleaning operations, should be avoided when a flammable atmosphere may be present.

18.3 Tanks Made from Conductive Nonmetallic Materials

Storage tanks made from conductive non-metallic materials (see 12.3.2) present no electrostatic hazards additional to those existing for metal tanks, provided they that are earthed and the precautions for metal tanks are fully implemented (see 17). Such tanks should be permanently marked as ‘Antistatic material’ or ‘Conducting material’.

18.4 High Resistivity Tanks Incorporating Conducting Elements

18.4.1 Electostatic hazards in the use of the tanks made from high resistivity materials can be minimized by the incorporation, on or just below the surface throughout the material, of a permanent robust conducting element, for example, a metal grid, connected to earth (see 12.3.6). Such tanks are supplied by specialist manufacturers who will usually advise on their suitability for specific applications.

18.4.2 The recommendations for metal storage tanks in 17.2 to 17.6 apply also to tanks incorporating conducting elements. To facilitate the earthing of personnel walking on a tank, a conducting walkway should be provided.

18.4.3 The liquid in the tank should be in direct contact with earth. If the conducting element covers the inner surface of the tank this provides the necessary earth connection. If the conducting element is not in contact with the liquid an earthed metal plate should be provided in the base of the tank with an area given by:

$$A = 0.04\ v$$

where

A is the area of the metal plate (in m^2), and
v is the volume of the tank (in m^3).

Experiments have demonstrated that this relationship is satisfactory for tanks with capacities up to and including 5 m^3 provided that the liquid is at no point more than 2 m from the earthed plate. For larger tanks, specialist advice should be sought but there appears to be no reason why the same relationship should not be valid.

18.4.4 Although rubbing may generate sufficient charge on the tank surface to give an incendive 'discharge, the probability that this will occur in normal practice is low. Nevertheless, vigorous rubbing of the surface, for example, in cleaning operations, should be avoided when flammable atmosphere may be present.

19 FIXED NON-METALLIC TANKS FOR THE STORAGE OF LIQUIDS SITED COMPLETELY BELOW GROUND

19.1 General

Tanks fabricated from non-metallic materials which are partly or completely above ground are considered in 18. The major differences when the tank is buried are in respect of tanks of high resistivity materials having a volume resistivity greater than $10^8 \Omega$ m and/or a surface resistivity greater than $10^{10} \Omega$. When buried, such tanks cannot be charged by external movement or rubbing. Also, the proximity of the earth all around the tank increases the electrical capacitance of its contents and, therefore, increases the amount of charge required to produce the break-down field strength inside the tank. The liquid may, however, still be insulated from earth and the possibility of an incendive discharge from its surface cannot be wholly excluded.

Recommendations for avoiding electrostatic hazards are given in 19.2 and **19.3.** They should be considered in conjunction with measures to deal with risks from other sources, for example, the general fire risk associated with the storage of large quantities of flammable liquids in non-metallic containers and mechanical strength limitations on larger containers.

19.2 Tanks Made of High Resistivity Materials

19.2.1 Large storage tanks made entirely of high resistivity materials and sited below ground should be individually designed for each specific application. Such tanks. are normally supplied by specialist manufacturers and the necessary risk assessment is usually carried out in consultation with the supplier. The degree of safety derived from the presence of earth around the tank depends on the maximum charge that can be produced and on the thickness of the tank wall. To confirm the safety of the installation it is necessary to show that the maximum charge produced in filling the tank does not produce a field strength at which a discharge can occur.

19.2.2 The whole of the outer surface of the tank, including the roof, should be in contact with the earth.

19.2.3 The liquid in the tank should be in direct contact with earth by means of an earthed metal plate in the base of the tank with an area given by:

$$A = 0{\cdot}04\ v$$

where

A is the area of the metal plate (in m^2), and
v is the volume of the tank (in m^3).

This relationship is satisfactory for tanks with capacities up to 5 m^3, provided that the liquid is at no point more than 2 m from the earthed plate.

For larger tanks specialist advice should be sought.

19.2.4 Provided that the design of the tank is in accordance with l-7.2.1, 19.2.2 and 19.2.3, the recommendations for metal storage tanks in 17.2 to 17.6 apply, except that the tank itself cannot be earthed.

19.3 Tanks Made of Conductive Non-metallic Materials

Buried storage tanks made from conductive non-metallic materials (see 12.3.2) present no electrostatic hazards additional to those existing for metal tanks, provided that they are earthed and the precautions for metal tanks are fully implemented (see 17). Such tanks should be permanently marked as 'Antistatic material' or 'Conducting material.'

20 GAUGING AND SAMPLING OF TANKS

20.1 General

There are static electricity hazards in the gauging and sampling of storage tanks and tanker cargo tanks. Electrostatic charge may be present in the liquid in the tank either because it is being pumped or because it is being subjected to agitation, for example, in a mixing operation (see 4). Charge may also be generated on the gauging or sampling equipment or on the personnel using the equipment.

An ignition hazard is created if such charges are generated in the presence of a flammable vapour/air mixture, mist or foam. An incendive discharge may occur between the liquid and the gauging or sampling equipment as they approach each other or between the equipment, or the personnel 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 20.2, 20.3 and 20.4 should be followed.

20.2 Materials of Construction, Earthing and Bonding

20.2.1 All metallic parts of gauging or sampling equipment should be connected to the tank, or if the tank is constructed of high resistivity material, directly to earth. For this purpose the connections may be metallic giving, a resistance to earth at all points less than 10Ω, or they may be of higher resistivity material, provided that the resistance to earth is low enough to relax any charge on the metal components (see 15). Thus the tape or cord may be of metal or of a natural fibre such as sisal or manila. A metal chain should not be used.

20.2.2 A high resistivity (synthetic polymer) cord or dip stick is not acceptable, unless it can be shown that a hazardous level of charge will not be generated. However, it is considered that small sampling containers of high resistivity materials are comparatively safer than similar metal containers (see 26.5).

20.2.3 Gauging and sampling equipment may be constructed entirely of natural or other materials, such as wood or natural fibres the, resistivities of which are such that they are unlikely to accumulate electrostatic charges or to give rise to discharges. Such equipment should be earthed.

20.2.4 Ensure that personnel engaged in gauging or sampling operations do not present an ignition risk (see 43.3.1). The problems this may present on board ships have been mentioned in 27.2.4.

20.3 Precautions with Systems Containing Conductive Components

20.3.1 Gauging and sampling should not be carried out while any charge generating operation is going on in a tank containing a flammable vapour/air mixture, mist or foam. These operations include the pumping into a tank of liquids with conductivities up to and including 50 pS/m and any cleaning procedures.

20.3.2 If a liquid with conductivity up to and including 50 pS/m and containing a separate water phase has been pumped into a tank or has been involved in a mixing operation in a tank, the tank should not be gauged or sampled until at least 30 minutes has elapsed after completion of the operation, unless it can be shown that charge relaxation is complete in a shorter period.

20.3.3 If a liquid with conductivity up to and including 50 pS/m but without a separate water phase has been pumped into a tank, the tank should not be gauged or sampled immediately after the cessation of the operation. A period of, say, 10 minutes should be allowed to elapse before gauging or sampling.

20.3.4 After a mixing operation involving a liquid with conductivity up to and including 50 pS/m, gauging or sampling should not take place while there is any settling of the components of the mixture.

20.3.5 If the liquid, or liquids, being pumped or mixed all have conductivities greater than 50 pS/m, gauging and sampling can take place at any time.

20.3.6 After a cleaning operation, gauging and sampling should be delayed until any charge mist generated has settled. This may take several hours.

20.3.7 The recommendations in 20.3.1 to 20.3.6 need not be followed with fixed gauging equipment or if the gauging takes place in a fixed, earthed dip pipe extending to the bottom of the tank.

20.4 Precautions in Adverse Weather Conditions

Gauging and sampling of flammable liquids should not be undertaken during thunderstorms, showstorms or hailstorms or where there is reason to believe that disturbed atmospheric electrical conditions could occur.

21 METAL ROAD/RAIL TANKS FOR LIQUIDS

21.1 General

Various liquid handling operations associated with road/rail vehicles can give rise to ignition risks due to static electricity. Examples are loading, gauging and sampling.. Charge on the liquid may be generated within the vehicle tank and/or in the pipeline system feeding the tank. Charging may also be associated with personnel undertaking tasks on the tank, such as gauging or sampling, or with cleaning operations. Charging arising in the equipment when transfer ring liquid to or from the vehicle is considered in 23.

An ignition hazard is created when charge is retained in the liquid, on insulated conductors or on personnel in the presence of a flammable vapour/air mixture, mist or foam. The flammable atmosphere in the tank may be due to the liquid currently being handled or to liquid carried in a previous load (switch loading operation). To avoid these hazards the recommendations given in 21.2 to 21.6 should be followed.

21.2 Earthing

21.2.1 The tank and its associated metal pipework and fittings should all be in good electrical contact with each other and with the main metal structure of the vehicle. During loading, the vehicle should be earthed directly or connected to the earthed loading gantry so that the resistance to earth is at all points less then 10 Ω. Electrical continuity checks should be made on the vehicle before it is brought into use, and subsequently where maintenance or modification could affect electrical continuity (see 15).

21.2.2 The tanks or compartments of new vehicles or of vehicles that have been out of service for repairs should be inspected, prior to the initial loading, for any potential floating objects, such as cans, which could form, insulated conductors. Such objects should be removed.

21.2.3 It should be ensured that personnel working on the vehicles do not present an ignition risk (see 43.3.1).

21.3 Loading

21.3.1 Splash filling into a tank where a flammable atmosphere may exist should be avoided, in order to prevent the formation of a charged mist. This can be achieved either by bottom entry or, if top loading is used, by the use of a fill pipe reaching to the bottom of the tank. Where filling is carried out through an open manhole or filling hatch not provided with an internal fill pipe, the hose or loading arm nozzle should be inserted to the bottom of the tank without actually touching it.

21.3.2 Entrained air or other gas should be avoided in liquids with conductivities up to and including 50 pS/m if there is any possibility of immiscible liquid or sediment on the tank bottom.

21.3.3 For liquids with conductivities up to and including 50 pS/m, the liner flow velocity in a pipe used for top loading should not exceed 1 m/s if a second immiscible phase is present; an example is water suspended in oil. In the absence of a second phase, charge generation increases with increasing flow velocity. The maximum linear flow velocity for top loading may be expressed in terms of a velocity, u, of the liquid flowing in a pipe section of diameter d. The velocity u is the lower of those given by the expressions:

$$u = 7$$

$$ud = \mathcal{N}$$

where u is in m/s, d is in m and $\mathcal{N}$ is in m²/s.

These expressions should be applied to the smallest diameter pipe section upstream of the tank or compartment being filled, except when the length of the section is less than 10 m and it is only one pipe size smaller than the next larger diameter pipe (that is, its diameter is not less than 67 percent of that of the larger). If both these conditions are satisfied the velocity u should be derived for the next larger size pipe.

$\mathcal{N}$ is a constant with a value of 0·5 m²/s for liquid conductivities above 5 pS/m. The value of $\mathcal{N}$ which should be applied for liquid conductivities up to and including -5 pS/m is a matter for debate; values of 0·38 m²/s and 0·5 m²/s have been accepted, there being only a very small degree of risk with either level.

If the length of the tank or compartment into which the single phase liquld is flowing is less than 2 m the velocity u in the pipe section to which it applies determines the maximum flow rate in the system. If the tank or compartment lenth, L, is between 2 m and 4·5 m the limiting velocity, u, may be increased by a factor $\sqrt{L/2}$ while if the length L is greater than 4·5 rn the limiting velocity should be 1·5 u, provided that the maximum of 7 m/s is not exceeded.

Bottom loading generates higher potentials at the liquid surface than top loading because of the absence of the earthed fill pipe. Therefore, unless an equivalent earthed fitting, such as a dip tube, standpipe or baffle plate, is mounted centrally in the tank, reaching from top to bottom, it is recommended that the flow rates for bottom loading should be 25 percent below those for top loading; calculated as above.

The flow rate established by the above procedure may be exeeded for a particular system and liquids if many years of experience with that system and liquids has demonstrated that it is safe to do so.

21.3.4 For liquids with conductivity greater than 50 pS/m the requirements of 21.3.2 and 21.3.3 can be disregarded. An antistatic additive may be used to raise the conductivity of a low conductivity liquid above 50 pS/m, -provided that it is compatible with the intended use of the liquid.

21.4 Filters

Fine particle filters installed in the pipeline system upstream of the vehicle can produce a significant amount of charge. It is recommended that the methods for dealing with the charge given in **30** are followed.

21.5 Gauging and Sampling

The introduction of equipment into a tank for gauging and sampling may produce additional static electricity hazards. It is recommended that the procedures given in 20 are followed.

21.6 Tank Cleaning with High Pressure Water Jets or Steam

These cleaning operations may give rise to static electricity hazards. It is recommended that the procedures given in 28 are followed.

22 NON-METALLIC ROAD/RAIL TANKS FOR LIQUIDS

22.1 General

The charging processes and static electricity hazards associated with metal road/rail tanks (see 21.1) are also encountered with non-metallic road/rail tanks. If tanks are made from high resistivity materials charge may also be generated and retained on the material itself by liquid handling operations or by internal or external rubbing. This presents additional hazards especially if there are insulated metal components, such as bolts, flanges or values or if the surface is contaminated with isolated areas of conductive material, such as water or grease.

As with metal tanks an ignition hazard is created when charge is retained on the liquid, on insulated conductors or on personnel in the presence of a flammable vapour/air mixture, mist or foam. The risk of an internal discharge from the liquid surface, for example, during dipping, is enhanced with high resistivity tanks both because the dissipation of charge from the liquid is impeded and because there is a greater field strength at the liquid surface. There is increased risk external to the tank if it is situated in a hazardous area, or is moved into such an area, owing to the possibility of charge on the tank itself, even when a non-flammable liquid is being handled. Also, personnel working on the tank may be insulated from earth.

Recommendations for avoiding electrostatic hazards are given in 21.2, 22.3 and 22.4. They should be considered in conjunction with measures to deal with risks from other sources, for example, the general fire risk associated with the carriage of large quantities of flammable liquids in non-metallic containers and mechanical strength limitations on larger containers, In applying these recommendations it will be necessary to bear in mind relevant national and international transport regulations.

22.2 Tanks Made of High Resistivity Material

22.2.1 The carriage of flammable liquids is not recommended in road/rail tanks completely fabricated from high resistivity materials, such as synthetic polymers and glass reinforced plastics, having a volume resistivity greater than $10^8 \Omega m$ and/or a surface resistivity greater than $10^{10} \Omega$.

22.212 Such tanks can be used for the carriage of non-flammable liquids, provided that the vehicle is not in, or does not move into, an area where there may be a flammable atmosphere.

22.3 Tanks Made from Conductive Nonmetallic Materials

Road/rail tanks made from conductive non-metallic materials (see 12.3.2) present no electrostatic hazards additional to those existing for metal tanks, provided that they are earthed and the precautions for metal tanks are fully implemented (see 21). Such tanks should be permanently marked as ‘Antistatic material’ or ‘Conducting material’.

22.4 High Resistivity Tanks Incorporating Conducting Elements

22.4.1 Electrostatic hazards in the use of tanks made from high resistivity materials can be minimized by the incorporation. on or just below the surface throughout the material, of a permanent robust conducting element, for example, a metal grid, connected to earth (see 12.3.6). Such tanks are supplied by specialist manufacturers who will usually advise on their suitability for specific applications.

22.4.2 The recommendations for metal road/rail tanks in 21.2 to, 21.6 apply also to tanks incorporating conducting elements. To facilitate the earthing of personnel working on a tank a conducting walkway should be provided.

22.4.3 The liquid in the tank should be in direct contact with earth, If the conducting element is not in contact with the liquid an earthed metal plate should be provided in the base of the tank, as recommended in 18.4.3.

22.4.4 Although rubbing may generate sufficient charge on the tank surface to give an incendive discharge, the probability that this will occur in normal practice is low. Nevertheless, vigorous rubbing of the surface, for example, in cleaning operations, should be avoided when a flammable atmosphere may be present.

23 TRANSFER OF LIQUIDS TO AND FROM ROAD/RAIL VEHICLES

23.1 General

Transfers between installations and road/rail vehicles are frequently carried out by means of’ fixed standpipes and/or flexible hoses and the operations can give rise to static electricity hazards. Additional ingition risks may be encountered when hose connections are made or broken, due to sparking from stray currents flowing in the hose string.

Three types of hoses are available, as follows:

a) *Conductive Hose* — This is made of material of high electrical resistivity with an embedded reinforcing wire and/or enshrouding wire braid or armouring incorporated during manufacture. These conducting components are bonded to the metal fittings permanently attached to the ends of the hose, so that when several lengths are coupled together there is a continuous low resistance electrical path along the entire run of the hose.

b) *Semi-Conductive Hose* — Part of the material of which this hose is made, usually its outer layer, has a conductivity high enough to disperse static electricity but low enough to restrict stray currents to safe limits, and this layer is in contact with the end fittings. The hose map have a metal reinforcing wire and/or enshrouding braid or armouring, but this is not in contact with the end fittings.

c) *Non-Conductive Hose* — This is mad of ematerial of high electrical resistivity without incorporated conducting wire or braid, and is incapable of dispersing static electricity.

The recommendations given in 23.2 to 23.5 inclusive are intended to guard against external electrostatic sparks when transferring flammable liquids, including loading into a road or rail tank with a flammable atmosphere due to a previous load (switch loading operations). Charging on the liquid, giving rise to hazards within such tanks, is dealt with in 21 and 22.

23.2 Earthing : **The Installation**

23.2.1 All metal parts of the installation should be in good electrical contact with each other and with earth, so that the resistance to earth and with earth, so that the resistance to earth is at all points less than 10 Ω. Electrical continuity checks should be made before the equipment is brought into use, and subsequently where maintenance or modification could affect continuity (*see* 15). Swivel joints in stand pipes and metal loading arms should be electrically continuous.

23.2.2 Whenever there is a possibility of a flammable atmosphere within or outside the vehicle tank, conductive or semi-conductive hose should be used. Non-conductive hose may itself become charged and if two or more such hoses are joined by metallic flanges these flanges may be capable of producing incendive sparks unless each is provided with a bonding cable to earth.

23.2.3 The resistance between the flanges of each length of conductive or semi-conductive hose should be checked with sufficient frequency to ensure that its conductive properties are being maintained.

23.2.4 It should be ensured that personnel working on the installation do not present an ignition risk (see 43.3.1).

23.3 Earthing of Road **Tankers**

23.3.1 Before the loading of such a vehicle is commenced, before any pipe connections are made and before any man lids are opened, its tank should be bonded to the appropriate earth point and the bond should remain in position throughout the operation. Automatic monitors are available to check the effectiveness of the earthing system.

23.3.2 In general, when a delivery is made from a road tanker to a storage tank, for example, at a petrol filling station, the hose couplings ‘to both the vehicle and the receiving tank will ensure adequate electrical continuity and earthing provided that this continuity is regularly monitored.

23.3.3 Liquefied petroleum gas road tankers, however, should be earthed during both loading and dis charging by being bonded to a suitable earth point. The bond should remain in position until the operation has been completed.

23.4 Earthing of Rail Tankers

23.4.1 Both rails of railway tracks where loading or unloading takes place should be bonded permanently to each other and to the earthed gantry or pipeline. The railcar itself is earthed by contact between its wheels and the rails. A separate flexible bonding cable between the tank and the pipeline is, therefore, not required unless doubt exists concerning the electrical continuity between the tank and the running gear. If a bonding cable is used, the recommendations given in 23.3.3 should be followed. If a railcar detector system requiring a resistance between the rails is in use, the value of the resistance should not be of such a magnitude as to prevent the safe dissipation of charge.

23.4.2 If an insulating flange is installed in a loading line to prevent the passage of stray currents, the filling nozzle should be bonded to the railcar by a flexible cable to ensure that the hose assembly downstream of the insulating flange is earthed. This connection should be made before the operation commences and should remain in place until it is complete.

24 LIQUID/LIQUID **AND** SOLID/LIQUID BLENDING **AND** MIXING

24.1 **General**

The mixting together of liquids or of liquids and solid particulate matter can give rise to static electricity ignition risks. Charge may be generated when the mechanical energy of the mixing process is expended in systems containing one or more low conductivity liquids. It is then retained on the continuous liquid phase, on suspended liquid or solid particulate matter, or on any insulated metallic object. If a flammable vapour/air mixture, mist or foam is present there is an ignition hazard and to avoid this the recommendations in 24.2 to 24.5 should be followed.

24.2 **Earthing**

24.2.1 All metallic parts of the equipment should be connected together and earthed so that the resistance to earth at all points is less than 10 Ω. If steam is used for. inerting, the nozzle of the steam hose should be earthed by an independent bonding wire, rather than relying on the conductivity of the hose itself.

'24.2.2 If a blending vessel has an internal insulating lining, relaxation of charge on the contents should be promoted by the provision of internal earthing, for example, the mounting of earthed metal strips or plates on or near the bottom of the vessel. This precaution may not be necessary if the lining is thin enough to permit charge dissipation or to avoid a dangerous surface potential (*see* 12.2.4).

24.2.3 It should be ensured that personnel working in the vicinity of a blending vessel do not present an ignition risk (see 43.3.1).

24.3 In-line Blending

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

24.3.2 The recommendations in 17 to 22 and 27 should be adopted, as appropriate, to avoid ignition hazards in the receiving tank arising from charge generated in the mixing operation or in subsequent flow to the tank.

24.4 Blending in Vessels or Tanks

24.4.1 The mixing of liquids produce a single phase of low conductivity is not considered to be unduly dangerous, provided that the normal precautions appropriate to liquid handling operations are taken (see 17).

24.4.2 If the resultant mixture contains dispersed liquid or solid particulate matter, it is advisable to minimize the generation of static electricity by increasing the condutivities of low conductivity liquids in the system by means of antistatic additives, provided that they are compatible with the intended use of the mixture.

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

24.4.4 If one or more of the dispersed phases is a solid the conductivity of the continuous phase may need to be much greater than 50 pS/m, and it may in addition be necessary to restrict the power input of the stirrer. As an example, in one operation a conductivity-of 1 000 pS/m was required with a power input limited to 0·37 kW/m^3 of the suspension. Each case should be considered on its merits, taking expert advice if necessary.

24.4.5 The gauging and sampling of wholly liquid systems should be carried out in accordance with the recommendations of 20. If there is a dispersed solid phase the precautions will depend upon the specific mixture aud no general advice can be given.

24.4.6 As an alternative to raising liquid conductivities, the vapour space in the blending vessel can be inerted. Restriction of the power output is then not required. The use of inerting agents should be in accordance with the recommendations of 43.

24.5 Jet Mixing

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

24.5.2 If a liquid has a low conductivity, an antistatic additive may be used to raise the conductivity above 50 pS/m, provided that it is compatible with the intended use of the mixture.

24.5.3 As an alternative to raising liquid conductivities, the vapour space in the tank can be inerted. The use of inerting agents should be in accordance with the recommendations of 43.

24.5.4 If a liquid has a low conductivity and neither the use of an antistatic additive nor inerting is possible, the hazard will depend upon circumstances and expert advice may be needed 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; an excessive 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; and
d) the time that has elapsed since the completion of a filling operation.

24.5.5 Gauging and sampling should be carried out in accordance with the recommendations of 20.

25 SMALL METAL CONTAINERS FOR LIQUIDS

25.1 General

This clause is concerned with metal containers that are easily portable or movable, rather than with such equipment as fixed storage tanks or road/rail vehicle tanks. Charge may be generated during the filling or emptying of such containers or during cleaning operations and an ignition hazard is created when charge is retained in the liquid, on insulated conductors or on personnel in the presence of a flammable vapour/air mixture, mist or foam. The flammable atmosphere may be due to the liquid currently being handled or to the previous contents of the container or it may be the result of conducting the operation in a hazardous area.

To avoid these hazards the recommendations given in 25.2 to 25.5 inclusive should be followed. In applying these recommendations it will be necessary to bear in mind relevant national and international transport regulations.

25.2 **Earthing**

25.2.1 During both filling and emptying, the container and all metallic parts of the system, such as funnels and nozzles, should be bonded together and / or earthed (see 15.3.1). Care should be taken to ensure that a metal funnel is not insulated from the container by a plastics bush. It is preferable to avoid the use of-plastics funnels; if they are used, particular care is needed to ensure that they do not lead to the insulation of any metal component.

25.2.2 It should be ensured that personnel engaged in filling, emptying or cleaning operations do not present an ignition risk (see 43.3.1).

25.3 Filling

25.3.1 For liquids with a conductivity less than 50 pS/m the linear flow velocity in the pipe entering the container should not exceed 1 m / s if a second immiscible phase is present; an example is water suspended in oil. In the absence -of a second phase, the limitations on flow rates imposed by present designs of filling stations, coupled with the avoidance of insulated conductors, have been adequate to maintain safe operations in containers up to 200 I.

25.3.2 For liquids with a conductivity greater than 50 pS/m the requirements of 25.3.1 can be disregarded. An antistatic additive may be used to raise the conductivity of a low conductivity liquid above 50 pS/m, provided that it is compatible with the intended use of the liquid.

25.3.3 Particular care is required in the filling of liquefied petroleum gas containers to ensure that earthing is effective at all times, for example, as follows:

a) All the metal-work of building plant and equipment should be electrically continuous and earthed. It may be advisable to use a common earthing system, within which the resistance to earth should not exceed 10 Ω at any point.

b) Weighing machine platforms should be electrically continuous with the weighing machine bases which should be connected to the earthing system.

c) The conveyor track should be electrically continuous and earthed.

d) If a fan ducting system is used it should be electrically continuous and earthed. At a joint where high resistivity material has been used, a flexible bond should be provided between adjacent lenghts of metal ducting.

e) Filling hoses should be semi-conductive or of an approved type (see 23).

25.4 **Filters**

Fine particle filters installed in the filling system upstream of the container can produce a significant amount of charge. This charge should be dealt with by the methods given in 30.

25.5 Cleaning

The container, the cleaning equipment and personnel carrying out the operation should all be earthed if there is any possibility of the presence of a flammable atmosphere within or outside the container.

26 SMALL NON-METALLIC CONTAINERS FOR LIQUIDS

26.1 General

This clause is concerned with non-metallic containers that are easily portable or movable, rather than with such equipment as fixed storage tanks or road / rail vehicle tanks. The great majority of these containers, however, are made from high resistivity materials having a volume resistivity greater than 10s Ω m and / or a surface resistivity greater than 10^{10} Ω m and it becomes necessary to consider the charge that may be generated and retained on the material itself by liquid handling or by internal or external rubbing. This presents additional hazards, especially if there are insulated conducting component, such as metal closures, or if the surface is contaminated by isolated areas of conductive material such as water or grease.

As with metal containers, an ignition hazard is. created when charge is retained on the liquid contents, on insulated conductors or on personnel in the presence of a flammable vapour/air mixture, mist or foam. The risk of an internal discharge from the liquid surface is enhanced with high resistivity containers both because the dissipation of charge from the liquid is impeded and because the field within the container is intensified at the liquid surface. There is increased risk external to the container if it is situated in a hazardous area, or is moved into such an area, owing to the possibility of charge on the container itself, even when a non-flammable liquid is being handled.

Recommendations for avoiding electrostatic hazards are given in 26.2 to 26.6. In applying these recommendations it will be necessary to bear in mind relevant national and international transport regulations. In the case of resistivity containers the precautions are considered in terms of” the hazardous zones defined in **4.12.**

26.2 Containers Made of High Resistivity Materials in Non-hazardous Areas

If a non-flammable liquid is being handled in an area where there is no possibility of a flammable atmosphere from another source, there is no ignition hazard and precautions against static electricity are not required.

26.3 Containers Made of High Resistivity Materials in Zone 2 Areas

26.3.1 The container can be considered to be safe in a Zone 2 area if a non-flammable liquid is being handled and the possibility of a flammable atmosphere from another source during normal operations is unlikely. The precautions in 26.3.2 to 26.3.6 should then be sufficient to avoid an ignition.

26.3.2 All conducting components, particularly metal funnels, should be earthed, metal caps and conductive labels should be avoided. Any adjacent metal objects should be earthed, for example, metal trollys with insulating wheels.

26.3.3 During filling operations the liquid should be in good contact with earth by means of 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.

26.3.4 The liquid flow rate during filling operations should not be greater than that recommended for an equivalent metal container (see 26.3.1).

26.3.5 Rubbing of the external surface of the container should be avoided, together with any other potential charging process, such as steam impingement.

26.3.6 It should be ensured that personnel in the vicinity of the container do not present an ignition risk (see 43.3.1).

26.4 Containers Made of High Resistivity Materials in Zone 1 Area

26.4.1 The container can be considered to be in a Zone 1 area if a flammable liquid is being handled, or if a non-flammable liquid is being handled and there is a possibility of the presence of a flammable atmosphere from another source during normal operations.

26.4.2 Containers of high resistivity materials should only be used in Zone 1 areas if it can be shown that the electrostatic ignition risk is acceptable. This requires a balance to be struck between the electrostatic risk and the protection afforded by a high resistivity container in other respects, such as corrosion resistance or advantageous behaviour in flame engulfment conditions; specialist guidance may be needed in reaching a decision. In general, the lower the conductivity of the liquid, the greater is the electrostatic risk. Also, as the volume of the container increases, both the electrostatic ignition risk and the scale of the ensuing fire increase.

26.4.3 When a high conductivity liquid is being handled, the precautions given in 26.3.2 to 26.3.6 are adequate in filling and emptying operations. If it can be established that charging of container itself can be kept to a low level it is permissible to use container sizes up to the maximum specified in relevant regulations.

26.4.4 When a low conductivity liquid is being handled and the precautions given in 26.3.2 to 26.3.6 are applied, a small electrostatic charge may remain but it is common practice to use high resistivity containers with capacities up to 5 l. Larger containers should be used only after specialist consultation.

26.5 Containers Made of High Resitivity Materials in Zone 0 Areas

In areas where a flammable atmosphere is present continuously, or for long periods, the use of high resistivity containers is not in general reconmmended, irrespective of the size of the container. There are exceptions; for example, small sampling containers of high resistivity materials for use in storage tanks are considered safer than similar metal containers. Expert advice should be comparatively sought to assess such cases.

26.6 Containers Made of Conductive Non-metallic Materials

Small containers made from conductive non-metallic materials (see 12.3.2) present no electrostatic hazards additional to those existing for metal containers, provided that they are earthed arid the precautions for metal containers, are fully implemented (see 25). Such containers should be permanently marked as ‘Antistatic material’ or ‘Conducting material’.

27 SHIPS (TANKERS) AND BARGES

27.1 General?

Various liquid handling operations associated with tankers and barges (both referred to subsequently as ‘ships’) can give rise to ignition risks due to static electricity. Examples are loading, gauging and sampling. Charge on the liquid may be generated within a tank and / or in the pipeline system feeding the tank. Charging may also be associated with personnel undertaking tasks on a tank, such as gauging or sampling, or with cleaning operations. An ignition hazard is created when charge is retained in the liquid, on insulated conductors or on personnel in the presence of a flammable vapour/air mixture, mist or foam. The flammable atmosphere in the-tank may be due to the liquid currently being handled or to liquid carried in a previous cargo. To avoid such hazards the recommendations given in 27.2 to 27.6 should be followed.

Certain sizes of tankers carrying crude oil or petroleum products having a flash point less than 60°C or other liquids having a similar fire hazard have to be provided with an inert gas system. This requirement does not apply to chemical tankers having a valid 'Certificate of Fitness for the Carriage of Dangerous Chemicals in Bulk'.

27.2 Earthing

27.2.1 Ships of metal construction are inherently earthed because they float in water. All metal fittings, pipework and associated equipment should be earthed to the ship (see 15). Electrical continuity checks should be made to establish that all metal parts of equipment such as valves and ullage devices are properly earthed to the ship. These checks should take place before the ship is brought into use, and subsequently whenever maintenance modification or deterioration could affect continuity,

27.2.2 The ship-shore loading line is normally conducting. It is customary to includein the line an insulating flange or a single length of non-conducting hose to prevent any hazards arising from stray currents due to any potential difference between ship and shore. All metal on the shore side of such a flange or hose length should be electrically continuous to the jetty earthing system and all metal on the seaward side should be electrically continuous to the ship.

A separate bonding cable between ship and shore is not required to avoid static electricity hazards.

27.2.3 Tanks in new ships or tanks that have been out of service for repairs should be inspected, prior to the initial fill, for any potential floating objects, such as cans, which could form insulated conductors. Such objects should be removed.

27.2.4 It should be ensured that personnel working in the vicinity of cargo tanks do not present an ignition risk (see 43.3.1). This may be difficult on board ship and it is advisable, therefore, to minimize the occurrence of flammable atmospheres, for example, by using a closed gauging system and avoiding open hatches. If a flammable mixture is possible, every effort should be made to prevent personnel from becoming charged, for example, by close attention to the materials used in dip tapes, etc. In many cases the marine environment is probably an alleviating factor.

27.3 Loading

27.3.1 Splash filling into a tank where a flammable atmosphere may exist should be avoided, in order to prevent the formation of a charged mist. This can be achieved by bottom entry or by the use of a fill pipe reaching to the bottom of the tank.

27.3.2 For liquids with conductivity up to and including 50 pS/m, the bottom entry or fill pipe should be designed to minimize turbulence and the agitation of any heavier immiscible liquid or sediment on the tank bottom.

27.3.3 Entrained air or other gas should be avoided in liquids with conductivities up to and including 50 pS/m if there is any possibility of immiscible liquid or sediment on the tank bottom.

27.3.4 For liquids with conductivity up to and including 50 pS/m the linear flow velocity in the pipe entering the tank should not exceed 1 m/s until the inlet has been covered, and maintained at 1 m/s if a second immiscible phase is present;. an example is water suspended in oil. A precise value for the safe maximum linear flow velocity in the absence of a second phase has not been established. However, experience indicates that the limitations on flow rate imposed by the present designs of pipeline systems have been adequate to maintain safe operations. There is no evidence that flow velocities up *to* and including 7 m/s are hazardous.

27.3.5 For liquids of conductivity greater than 50 pS/m the requirements of 27.3.2 to 27.3.4 can be disregarded. An antistatic additive may be used to raise the conductivity of a low conductivity liquid above 50 pS/m, provided that it is compatible with the intended use of the liquid.

27.4 Filters

Fine particle filters installed in the pipeline system upstream of the cargo tank can produce a significant amount of charge. It is recommended that the methods for dealing with the charge given in 30 are followed.

27.5 Gauging and Sampling

The introduction of equipment into a tank for gauging and sampling may produce additional, static electricity hazards. It is recommended that the procedures given in 7 are followed.

27.6 Tank Cleaning

Tank cleaning by high pressure jets in recognized to be a potential static electricity hazard. Reference should be made to 28.

28. TANK CLEANING WITH HIGH PRESSURE WATER JETS OR STEAM

28.1 General

The techniques for cleaning tanks cover a very wide range, including the-use of water or oil jets. and the impingement of steam. In some cases the cleaning liquid is recycled and this may lead to a two phase liquid, for example, an oil-in-water suspension, and the system may also be complicated by the inclusion of surface-active chemicals.

Most of the techniques can give rise to electrostatic charge, and the operation becomes hazardous if the charge is retained on insulated conductors, bulk liquid or mist in the presence of a flammable vapour/air mixture, mist or foam. The subject is highly complex and not yet fully understood; general advice on the avoidance of hazardous discharges is given in 28.2 to 28.4.

In tank cleaning procedures it is highly probable that hazards other than those due to static electricity may be present, and reference should, therefore, be made to other appropriate documents. In this Code no recommendations are included for tank cleaning using hydrocarbons or other organic solvents. The spraying of these materials can generate large amounts of static electricity and at the same time produce a flammable atmosphere, and specialized procedures are required to carry out such operations safely.

28.2 Earthing

28.2.1 All metallic components in the cleaning system should be in good electrical contact with each other and with earth, using bonding connections if necessary, so that the resistance to earth at all points is less than 10 Ω. The tank itself and its associated pipework and fittings, if of metallic construction, should be similarly earthed.

28.2.2 It should be ensured that personnel working on the tank do not present an ignition risk (see 43.3.1).

28.2.3 The effects of high resistivity materials, such as synthetic plastics, in either the cleaning system or the tank structure should be carefully assessed before they are used where a flammable vapour/air mixture, mist or foam may be encountered.

28.3 Additional Safety Measures

28.3.1 Earthing will remove one hazard but there may remain hazards arising from the electrostatic charge generated in the tank space. Risks from this can be eliminated either by control of the flammable atmosphere or by restricting the space potential. Methods of achieving safety will depend on the industry concerned.

28.3.2 Wet steam-in particular presents a source of very high charge generation. Safety should, therefore, be based on the removal of the flammable atmosphere before steaming, unless it can be shown that dangerous potentials are not produced in the -particular operation.

28.4 Gauging -and Sampling

The introduction of equipment into a tank for such operations as gauging should be avoided as far as possible during tank cleaning. If gauging is considered to be essential the recommendations in 20 should be scrupulously followed.

29 AIRCRAFT FUELLING

29.1 General

Aircraft are most frequently fuelled by means of mobile fuellers or by hydrant systems feeding the aircraft system through mobile dispensers. Fuel transfers are made through flexible hoses and ignition hazards due to static electricity may arise during the operations. Charge may be generated on the fuel in the system feeding the aircraft or in the aircraft tank, which is normally of metal construction, In addition, charge accumulates on the aircraft itself during flight and, if insulated, it can, in some atmospheric conditions, become charged whilst on the ground.

Although not an electrostatic hazard, the possibilily exists of sparking when making or breaking hose connections. Sparks are due to stray currents arising from, for example, electrical power installations or cathodic protection systems. -Precautions against static electricity ignitions need, therefore, to be consistent with the avoidance of stray current sparking.

Recommendations for avoiding static electricity hazards are given in 29.2 to 29.4. They assume the presence in the fuelling system of a fine particle filter and/or a water separator.

29.2 Hoses

29.2.1 Flexible hoses should preferably be of the semi-conductive type (see 23.1) so as to facilitate the dispersion of static electricity while limiting stray current flow. If conductive hose is used in a hydrant system, an insulating flange should be inslalled at the end of the hydrant riser. The use of 'non-conducting hoses should be limited to situations where a flammable atmosphere is not likely to be present and where charging of the outer surface is unlikely, for example, where the hose lies on the ground.

29.2.2 The resistance between the end flanges of each length of conductive or semi-conductive hose should be checked with sufficient frequency to ensure that its conductive properties are being maintained.

29.3 Earthing and Bonding

29.3.1 All the metallic parts within each fuelling vehicle should be in good electrical contact with each other, so that the resistance between any two points on each unit is less than 10 Ω. Similar electrical continuity should exist within the hydrant system and also within each hydrant dispenser.

29.3.2 It is recommended that fuelling vehicles and hydrant dispensers should have antistatic tyres. Aircraft are normally equipped with such tyres.

29.3.3 Although the aircraft should be earthed through tyres, additional earthing is sometimes provided by means of a bonding cable betwen the aircraft and an earthing point in the concrete apron. This connection should be made only to an earthing rod provided for the purpose; on no account should hydrant pits or pit valves be used, owing to the possibility of stray current sparking. The connection should be direct from the aircraft to the earthing rod and independent of the fuelling vehicle or hydrant dispenser.

29.3.4 A bonding connection should be made between the aircraft and the fuelling vehicle or hydrant dispenser before any fuel system connections are made and should remain in position until the operation has been completed and all fuel system connections have been broken. For this purpose the fuelling vehicle or dispenser should carry a cable firmly connected to the vehicle, and this connection should be tested with sufficient frequency to ensure that its resistance remains below 10 Ω (see 15).

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

29.3.6 There should be a direct bond between the aircraft fuelling orifice and the metallic end of the fuelling hose. With underwing fuelling the necessary connection is achieved by the metal-to-metal contact between the hose end coupling and the aircraft fuelling, adaptor. With overwing. fuelling the hose nozzle should be bonded to the aircraft by a separate cable before the filler cap is removed and the bond should remain in position until the operation has been completed and the filler cap replaced.

With some light aircraft bonding may not be possible because of the absence of a bonding lug near the fuelling orifice, and a semi-conductive hose is then strongly recommended.

29.3.7 Some over wing operations may require the use Qf a funnel. This should be metallic and should be bonded both to the fuelling nozzle and to the aircraft before the aircraft filler cap is removed.

29.3.8 Earthing and bonding procedures similar to the above apply also to fuel deliveries to aircraft from drums and other containers.

29.3.9 It should be ensured that personnel do not present an ignition risk (see **43.3.1**).

29.4 Fuelling **Rate**

During the fuelling of aircraft, liquid velocities in the delivery system or the aircraft fuel manifolds often exceed the levels recommended for road/rail vehicles (see 21.3.3). However, aircraft tanks have large horizontal areas and little depth and this reduces the hazard of the fuelling operation. The majority of aircraft fuels contain an anti-static additive and, where this is known to be present, flow rates up to 7 m/s are acceptable. Where no additive is used the recommendations of the Civil Aviation Authority should be followed.

30 FINE PARTICLE FILTERS AND WATER SEPARATORS

30.1 General

The presence of a fine particle filter and/or a water separator in a pipeline system can greatly increase electrostatic charge generation in a liquid, because the very large surface area of the filter or separator medium promotes extensive charge separation as the liquid passes through it. Typical charge densities in the liquid leaving such a device can be in the range 10 $\mu C/m^3$ to 5 000 $\mu C/m^3$ that is, up to several orders of magnitude greater than those encountered in pipelines. Coarse strainers and gauzes do not normally cause any significant charge generation.

If a flammable vapour/air mixture, mist of foam is present in the tank downstream of the filter or water separator there is an ignition hazard and, to supplement the recommendations for tanks given in 20 to 22 and 27, the measures in 30.2 to 38.6 should be adopted.

30.2 Earthing

30.2.1 All metallic parts of fine particle filters and water separators should be connected to each other and to earth, so that the resistance to earth at all points is less than 10 Ω (see 15).

30.2.2 It should be ensured that personnel do not present an ignition risk (*see* 43.3.1).

305 Charge Relaxation

The charge generated in the fine particle filter or water separator can be dissipated by the provision of sufficient residence time between the device and the receiving tank. This may be achieved by including in the line between them a metal relaxation chamber; in some cases there may be sufficient residence time in the pipeline, which should be of metal construction and earthed, without the need for a special chamber.

For liquids with conductivities down to 2 pS/m the residence time should be 3τ, where τ is the relaxation time of the liquid, and for less conductive liquids it should be 100 s. The relaxation time is given by the equation:

$$\tau = \frac{\varepsilon\varepsilon_0}{\gamma} \times 10^{12}$$

where

τ is the relaxation time (in s),

ε is the relative permittivity of the liquid,

ε_0 is the permittivity of free space (8.85×10^{-12} F/m), and

y is conductivity of the liquid (in pS/m).

Thus, for a liquid with a relative permittivity of about 2, the residence time is about 50 μs.

Disadvantages of the relaxation procedure are:

a) the range of conductivities needs to be known at the design stage;
b) low conductivity liquids require large relaxation chambers;
c) these chambers have always to be kept completely full during pumping operations, to avoid the ignition hazard which would occur in the vapour space above the liquid.

30.4 The Use of Antistatic Additives

The residence time required down-stream of a fine particle filter of water separator may be reduced by using an antistatic additive to increase the conductivity of the liquid, provided that it is compatible with the intended use of the liquid.

30.5 The Use of Floating Tanks or Floating Blankets

If the use of a relaxation chamber or an antistatic additive is not possible, liquid may be pumped directly from a fine particle filter or water separator into a floating roof tank, or into a fixed roof tank equipped with an earthed conducting floating blanket. The precautions given in 20.7 and 20.8 should be adopted. Until the floating roof or blanket is buoyant the flow rate should be low enough to allow relaxation before the liquid enters the tank. Thereafter, the flow rate can be increased to that normally acceptable for the tank.

30.6 Filling and Emptying

Fine particle filters and water separators should be filled and emptied slowly, and on no account should they be emptied by means of compressed air.

31 METAL CONTAINERS AND TANKS WITH A FIXED INTERNAL NON-METALLIC COATING, FOR THE STORAGE AND TRANSPORT OF LIQUIDS

31.1 General

The charging processes and static electricity hazards associated with metal containers (see 17.1) still apply when the container has a fixed internal non-metallic coating. If the coating is made from high resistivity material, charge may also be generated and retained on the coating itself by the liquid handling operations or by internal rubbing. An ignition hazard is created when charge is retained on the liquid, on insulated conductors, on the coating itself or on personnel in the presence of a flammable vapour/air mixture, mist or foam. The risk of a discharge from the liquid surface, for example, during gauging, depends upon the rate of charge input, the volume of the container, the conductivity of the liquid and the thickness and conductivity of the coating.

Recommendations for avoiding electrostatic hazards are given in 31.2 and 31.3. They should be considered in conjunction with measures to deal with other hazards that may arise in the storage and transport of flammable liquids.

31.2 Containers with an Internal High Resistivity Coating

31.2.1 There should be good contact between the container and the coating.

31.2.2 Provided that the precautions recommended for the equivalent uncoated container are applied (see 17, 21, 25 and 27), internal coatings such as paint, with a thickness less than 2 mm are unlikely to create hazards additional to those normally expected in an uncoated container, except where there are rapid fillings.

31.2.3 For layers thicker than about 2 mm, or where there is a possibility of rapid repeat fillings, the precautions for an equivalent uncoated container should be supplemented by providing a conducting path between the liquid contents and earth. For conducting liquids this path can be, for example, and earthed metal fill pipe or dip pipe extending almost to the bottom of the container but not touching it. Additional earthing may be needed for low conductivity liquids, depending on the type and thickness of the coating, the size of the container and the conductivity of the liquid. The conductivity level at which additional earthing is likely to be needed is not definitely established, but it should not be necessary if the conductivity exceeds 50 pS/m for storage tanks or 1 030 pS/m for tanks in which blending is taking place.

31.2.4 The inner surface should not be rubbed in the presence of a flammable vapour/air mixture, mist or foam. This is important when cleaning a container that has held a flammable liquid. Flammable solvents should not be used for cleaning the inside of a container.

31.3 Containers with an Internal Conductive Coating

Coatings made from conductive non-metallic materials (see 12.3.2) are acceptable provided that the precautions recommended for equivalent uncoated metal containers are applied (see 17, 21, 25 and 27).

32 METAL CONTAINERS FOR LIQUIDS WITH OUTER NON-METALLIC COATINGS OR JACKETS

32.1 General

The charging processes and static electricity hazards associated with metal containers (see 17.1) are still encountered when the container has a non-metallic coating on its outer surface. If the coating is made from high resistivity material, charge may also be generated and retained on the coating itself when subjected to processes producing high charging rates, for example, -excessive rubbing. In some designs of container the high resistivity coating supports metallic components not in contact with the main metal container and these can be a source of discharges if not earthed. However, the presence of the coating in close contact with the metal provides a system of relatively high capacitance and a large amount of charge is required on such components to raise their potentials sufficiently to give rise to incendive discharges. Personnel walking on such high resistivity coatings may also be insulated from earth.

An ignition hazard is created when charge is retained on the liquid, on insulated conductors, on the coating itself or on personnel, in the presence of a flammable vapour/air mixture, mist or foam. Recommendations for avoiding electrostatic hazards are given in 32.2 to 32.4. They should be considered in conjunction with measures to deal with other hazards that may arise in the storage and transport of flammable liquids.

32.2 Containers with an Outer High Resistivity Coating

32.2.1 The metal container and any metallic components in the vicinity, including those mounted on the high resistivity coating, should be earthed.

32.2.2 It should be ensured that personnel do not present an ignition risk (see 43.3.1). Where appropriate, conducting walkways should be provided.

32.2.3 The full range of precautions recommended for an equivalent uncoated container should be applied.

32.2.4 In most situations coatings, such as paint, with a thickness less than 2 mm are unlikely to create hazards additional to those expected with an uncoated container, provided that all the precautions for the uncoated container are applied. In processes where the rate of external charge generation is very high, for example, electrostatic spraying, there is a possibility of a propagating brush discharge (see 7.4).

32.2.5 For coatings thicker than 2 mm the hazard depends on such variables as the external charge generating mechanism and the thickness and resistivity of the coating and each situation should be considered on its merits, taking expert advice if necessary. In processes where the rate of external charge generation is very high, for example, electrostatic spraying, there is a possibility of a propagating brush discharge (see 7.4).

32.3 Containers with an Outer High Resistivity Coating Protected by an Earthed Conducting Sheath

A conductor on which an outer coating of high resistivity material is completely covered by a permanent earthed sheath of conducting material is acceptable irrespective of the thickness of the high resistivity coating. The inner metallic container should be earthed and all the precautions recommended for an equivalent uncoated container should be applied.

32.4 Containers with an Outer Conductive Coating

Coatings made from conductive non-metallic materials (see 12.3.2) are acceptable provided that the precautions recommended for equivalent uncoated metal containers are applied.

33 PIPELINES FOR LIQUIDS AND GASES

33.1 General

When a liquid flows in a pipe, charge separation occurs between the liquid and the internal surface of the pipe, producing electrostatic charges on both the liquid and the pipe, in the case of a pure gas, or a mixture of pure gases, flowing through a pipe there is no generation of static electricity. However, in practice, gases often contain solid or liquid particulate matter and charge can then be generated where these particles impinge on the walls of the pipe or on obstructions such as orifices or valves.

The extent to which the charges are retained depends upon the resistivity of the pipe material and upon the conductivity of the pipe contents in the case of liquids. High resistivity pipes may have metallic components, such as flanges or valves, and these may retain charge if they are not earthed.

In addition to charge generation within the pipe by liquid or gas flow, charging processes, such as rubbing or steam impingement, can lead to the accumulation of charge on the outer surface of a high resistivity pipeline and on any insulated metal components in the line.

Potentials high enough to cause incendive discharges can be generated by the flow of both flammable and non-flammable liquids and gases. If such discharges do occur the hazard external to the pipeline depends upon the presence of a flammable atmosphere adjacent to the pipe, which may be due to leakage from the pipe itself if its contents are flammable, or to flammable gas or vapour from some other source. Also, if the liquid or gas in the pipe is flammable, there may be, an internal ignition risk if air enters the system and produces a flammable mixture within the pipe.

It should be noted that the use of plastics pipelines with flammable liquids or gases may be restricted by requirements imposed by the general fire risk.

To avoid the ignition hazards that may arise in various situations, the recommendations given in 33.2 to 33.7 inclusive should be followed.

It should be noted that these refer to pipeline flow situations and additional precautions may be necessary if the line contains any elements, such as fine filters, capable of high charge generation.

33.2 Avoidance of a Flammable Atmosphere

When a flammable atmosphere external to a pipe is due to a leak of flammable gas or liquid from the pipe, the escape should be stopped as soon as possible by closing valves or, in the case of a flexible non-metallic pipe, by the application of mechanical clamps on either side of the leak. If the presence of a flammable atmosphere is considered possible, personnel should be earthed. (see 43.3.1).

33.3 Metallic and Conductive Non-metallic Pipes Above Ground

All parts of the pipeline should be earthed, including any metal cladding netting reinforcement of ‘coatings. The criterion for satisfactory earthing is that the resistance to earth at any point should not exceed 10^8 Ω, although a’ resistance not exceeding 10 Ω should be obtainable in a wholly metallic system (see 15.2.2 and 15.3.4).

33.4 High Resistivity Pipes Above Ground

33.4.1 All metallic components in the pipeline system, including any metal cladding or netting reinforcemnt of coatings, should be earthed with a maximum resistance to earth of 10^8 Ω to (*see* 15.2.2).

33.4.2 The transfer of gases and low conductivity liquids (conductivity up to and including 100 pS/m) through high resistivity pipes is not, in general, recommended in Zones 0, 1 and 2 hazardous areas (see 4.12). If the use of such a pipeline in these circumstances is considered to be essential, the electrostatic hazard should be carefully evaluated, using expert advice, if neccssary.

33.4.3 When a high conductivity liquid (conductivity above 100 pS/m) flows in a high resistivity pipe it prevents the accumulation on the inner surface of the pipe of sufficient charge to cause a hazardous field outside the pipe, provided that the liquid is in contact with earth at some point, for example, in an earthed metal tank or valve. The presence of high resistivity pipelines carrying high conductivity liquids is, therefore, acceptable in Zones 0 and 1 areas if the liquid is earthed in this way, if all metallic components are earthed and if there are no external sources of electrostatic charge generation, such as rubbing or steam impingement. They are also acceptable in Zone 2 areas with the same provisos, except that external sources of electrostatic generation can be tolerated if it can be shown that the consequent ignition risk is low, that is, comparable with the ignition risk from Zone 2 electrical equipment.

33.5 Buried Pipelines

33.5.1 When a pipe is buried its whole external surface is in contact with the earth and no further earthing of matallic or conductive pipe or of metallic components of high resistivity pipelines is required. If a high conductivity liquid (conductivity greater than 100 pS/m) is being carried in a high resistivity pipeline steps should be taken to ensure that the liquid is earthed at some point, such as an earthed metal tank or valve.

33.5.2 When a metallic or conductive pipeline is exposed by excavation it remains in contact with earth at both ends of the excavation and it requires no further earthing.

33.5.3 When a high resistivity pipeline is exposed by excavation any metallic components in the excavated section of pipe should be earthed if there is any possibility of the presence of a flammable atmosphere.

3X5.4 For all types of buried pipelines, when exposed by excavation adjacent conductors should be earthed if the presence of a flammable atmosphere is suspected. It is very hazardous to make the earthing connection to an insulated conductor while flammable gas or vapour is present.

33.6 Ignition Hazard Within a Pipeline

If a flammable mixture occurs in a pipeline due the inadvertent ingress of air the risk of an electrostatic ignition may be very high, depending on circumstances, and flow should be stopped until the risk has been evaluated. Intentional pumping of a flammable mixture should never be attempted without taking expert advice.

33.7 Valves

It is important when using ball valves in such systems that they are fitted with antistatic devices.

34 CONTAINERS FOR HIGH RESISTIVITY POWDERS

34.1 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. When the highly charged particles are bulked in a container discharges occur between the powder and the container (see 11.3) and these constitute an ignition hazard if a flammahle vapour/air mixture or powder suspension in air is present. Other discharges may also occur involving the container or personnel in its vicinity and these also present ignition hazards. In the case of a container of high resistivity material the discharges from the powder to the container may lead to polarization across the thickness of the container wall and to the risk of a propagating brush discharge if an earthed conductor or person approaches the inner surface (see 12.2.3). Such a discharge is not only highly incendive but can cause severe physiological shock. High resistivity containers can also be charged externally by rubbing or by other charge generating mechanisms, such as steam impingement; these charges may constitute an ignition hazard.

To avoid these hazards the recommendations given in 34.2 and 34.3 should be followed. The specific case of a removable liner in a container is included in 35.

The phenomena are complex and in many instances it may be appropriate to take expert advice.

~34.2 Metallic and Conductive Non-metallic Containers

34.2.1 The container and any metallic equipment in the vicinity, including the fill pipe, if present, should be earthed.

34.2.2 For containers with capacities up to and including 5 m^3 in the presence of flammable mixtures of materials with minimum ignition energies greater than 25 mJ, earthing of equipment should provide adequate protection. However, if a suspension in air of a powder with a minimum ignition energy less than 100 mJ could occur, personnel should also be earthed (see 43.3.1).

34.2.3 'For containers of capacities up to and including 5 m^3 where a flammable mixture could occur of any material with minimum ignition energy up to and including 25 mJ, protective measures additional to the earthing of equipment and personnel should be considered to deal with discharges from the bulked powder, although practice has shown that such additional precautions are seldom needed. If it is found that incendive discharges are possible, the protective measures that may be used include the reduction of the quantity of charge on the incoming powder, for example, by neutralization using ionized air, or the installation of some form of explosion protection, such as inerting, air purging, explosion suppression or explosion venting.

34.2.4 For containers with capacities exceeding 5 m^3 and containing a flammable atmosphere there is an as yet unknown probability of an incendive discharge from the charged powder suspension in air. In addition to the earthing of equipment and personnel, consideration should therefore be given to installing some form of' explosion protection, as mentioned in 34.2.3, unless it can be he shown that discharges from both the suspended and the bulked powder will not occur.

34.3 Containers of High Resistivity Materials

34.3.1 The recommendations given in 34.3.2 to 34.3.9 apply to containers fabricated from materials having a volume resistivity greater than $10^8 \Omega$ m and/or a surface resistivity greater than $10^{10} \Omega$.

34.3.2 If the contents of the container are solvent-wet and can produce a flammable atmosphere the advice given in 26.4 and 26.5 for flammable liquids in high resistivity containers should be followed.

34.3.3 Any metallic equipment in the vicinity of the container, including the fill pipe, if present, should be earthed.

34.3.4 For dry powders in containers with capacities up to and including 5 m^3, in the presence of flammable mixtures of materials with minimum ignition energies greater than 25 mJ, earthing of metallic equipment should provide adequate protection. It should also be established that the rate of charge input with the powder is insufficient to promote propagating brush discharges. If a suspension in air of a powder with a minimum ignition energy less than 100 mJ could occur personnel should also be earthed (see 43.3.1 j.

34.3.5 For dry powders in containers with capacities up to and including 5 m^3, where a vapour/air mixture or dust suspension could occur of any material with a minimum ignition energy up to and including 25 mJ, protective measures additional to the earthing of equipment and personnel should be considered to deal with discharges from the bulked powder, if it cannot be shown that the quantity of charge present is insufficient to cause incendive discharges. These protective measures include the reduction of charge on the incoming powder, for example, by neutralization using ionized air, or the installation of some form of explosion protection, such as inerting, air purging, explosion suppression or explosion venting.

34.3.6 For dry powders in containers with capacities up to and including 5 m^3, where propagating brush discharges, giving rise to physiological shock, are possible, one or more earthed rods may be inserted into the container to assist relaxation, of charge from the powder. Precautions as given in 34.3.5 are still required if a vapour/air mixture or dust suspension could occur of any material with a minimum ignition energy up to and including 25 mJ.

The possibility of a propagating brush discharge can be reduced by prebulking the incoming powder in an earthed metal hopper. The precautions given in 34.2 should be applied to the hopper.

34.3.7 For containers with capacities exceeding 5 m^3 there is as yet an unknown probability of an incendive discharge from the charged powder suspension in air. In addition to the earthing of equipment and personnel, consideration should therefore be given to installing some form of explosion protection, as mentioned in 34.3.5, unless it can be shown that discharges from both the suspended and the bulked powder 'will not occur. The insertion of earthed rods should also be considered if there is any risk of physiological shock to personnel owing to propagating brush discharges.

34.3.8 If the container and its contents are in, or are moved into, an area where a flammable atmosphere could be present, rubbing of the surface of the container should be avoided, together with any other charging process such as steam impingement.

34.3.9 Powder should not be emptied from a high resistivity container in presence of a flammable atmosphere. When the powder itself is liable to produce a sensitive dust cloud (minimum ignition energy less than 25 mJ) then, ideally, high resistivity containers should not be used unless it can be shown that the charge levels developed during pouring do not produce incendive discharges.

35 REMOVABLE NON-METALLIC LINERS IN CONTAINERS FOR SOLVENT-WET MATER-IALS OR DRY POWDERS

35.1 General

In some operations, particularly the handling of solvent wet or dry powders in drums, it is convenient to use an inner liner, such as a plastics bag, as a precaution against contamination. If made of high resistivity material, such a liner can be charged during filling and emptying. Dangerous potentials can be generated if the liner is removed from the container because of the separation of charges which then occurs. In some processes, for example, when filling the container with a highly charged high resistivity powder, there is a possibility of a propagating brush discharge from the liner (see 7.4'). In addition to these consequences of charging the liner, it may also insulate the material being handled from earth, even though the conducting outer container is earthed. The discharges that may occur in operations with high resistivity liners can give rise to an ignition hazard if a flammable vapour/air mixture is present. Sensitive dust clouds may in principle be ignited and the possibility of such ignition should be assessed for dust clouds of minimum ignition energy less than 25 mJ. A propagating brush discharge would be much more incendive and could also cause serious physiological shock. Recommendations for avoiding these hazards are given in 35.2 and 35.3.

35.2 Liners of Conductive Materials in Metal or Conductive Containers

35.2.1 If a non-metllic liner is used in circumstances where there may be an ignition hazard, or where propagating brush discharges giving rise to physiological shock are possible, it is strongly recommended that the liner should be conductive with a surface resistivity not exceeding $10^{11}\Omega$.

35.2.2 All the precautions recommended for the equivalent unlined container should be applied (see 34.2).

35.3 Liners of High Resistivity Materials in Metal or Conductive Containers

Liners with surface resistivities greater than $10^{11}\Omega$ should be used only if they are essential, for example, for reasons of chemical compatibility between the liner and the material being handled. The ignition risk and the possibility of physiological shock from propagating brush discharges depends very much on the thickness and resistivity of the liner, the handling procedure, the electrical properties of the materialbeing handled and the nature of any flammable mixture that may be present. Each situation should be considered on its merits, taking expert advice, if necessary.

35.4 Liners in High Resistivity Containers

The precautions required are the same as those for the handling of powders in high resistivity containers in the absence of a liner (see 34.3). The use of conductive liners within high resistivity containers is not generally recommended because of the danger that they will remain electrically isolated and contribute towards an ignition hazard. Conductive liners should therefore only be used with high resistivity containers if the liner is effectively earthed.

35.5 Removal of Liner

An essential precaution in almost all situations is that the liner should not be removed from the container, for example, to shake out any residue, if there is a possibility of the presence of a flammable vapour/air mixture or a sensitive dust cloud.

36 MANUAL ADDITION OF POWDERS TO FLAMMABLE LIQUIDS

36.1 General

A significant number of fires/explosions during the manual addition of powder from drums (metal or plastics) and sacks (paper or plastics) to flammable liquids have been attributed to electrostatic discharges. Electrostatic charge is generated by the pouring of the powder down any chute into the receiving vessel. If this charge is permitted to accumulate then potentials can be developed on the container being emptied, any liner in this container, the receiving vessel, loading chute, powder stream, vessel contents and personnel carrying out the operation.

For reasons of general fire and toxicity risk the flammable vapour should be contained within the receiving vessel and the formation of dust clouds around the loading point should be strictly controlled. In the following precautions it has been assumed that flammable vapour and dust clouds will be formed only within the receiving vessel and the immediate vicinity of the entry point.

The elimination of flammable atmospheres can provide one basis for safe operation. Alternatively, the recommendations given in 36.2 to 36.7 should be followed to avoid an electrostatic ignition.

36.2 Container being Emptied

36.2.1 Metal, Paper and Conductive Non-metallic Containers

These should be earthed (see 15) prior to being emptied and remain earthed when in the presence of a flammable atmosphere. In the case of a paper sack the use of an earth clip may not be very practicable and the sack can be earthed by contact with the earthed plant.

36.2.2 High Resistivity Non-metallic Containers

In areas where a flammable atmosphere is present, the use of high resistivity containers is not, in general, recommended except in situations in which the flammable atmosphere does not come into contact with the container. Sensitive dust clouds may in principle be ignited and the possibility of such an ignition should be assessed for dust clouds of materials of minimum ignition energy less than 25 mJ.

36.3 Liner

The precautions in 35.3 to 35.5 should be applied.

36.4 Receiving Vessel/Loading Chute

36.4.1 *Metal and Conductive Non-metallic Items*

These should be earthed (see 15).

36.4.2 *High Resistivity Items*

In general, the use of receiving vessels and loading chutes fabricated completely from high resistivity materials is not recommended (see 18.2).

36.5 Powder Stream

The conditions under which an incendive discharge could be released by the electrostatically charged powder stream as it enters the receiver cannot be precisely defined. Available evidence suggests that, with two possible exceptions, this does not present an ignition risk. The exceptions are:

a) if the length of the charge chute exceeds 2 m, or

b) if high resistivity powders are involved.

In both situations the risk is considered to be low in the majority of operations but it is recommended that expert advice should be sought when these conditions exist.

36.6 Vessel Contents

36.6.1 Liquid of Conductivity Greater than 50 pS/m

There is no hazard provided that the liquid is in contact with earth. In an uncoated metal receiver. the earthing system for the receiver provides the necessary earth path. If the liquid is insulated from earth by a lining then a special earth point should be provided near to the base of the receiver.

36.6.2 Liquid of Conductivity Less than 50 pS/m

A dangerous level of charge may be retained on the liquid. The degree of risk depends on the conductivity of the liquid and the levels of charge generated during the loading operation. Ideally the liquid should be made conducting by the use of a suitable antistatic additive. If this cannot be done then expert advice should be sought to establish a safe procedure.

36.7 Earthing

It should be ensured that personnel do not present an ignition risk (see 43.3.1).

37 RELEASE OF GASES AND VAPOURS

37.1 General

Gas issuing under. pressure from an orifice very frequently carries with it liquid or solid particulate matter. This may be a condensed phase of the gas itself, such as carbon dioxide snow or water droplets in wet steam, or it may be a different material, such as rust or dirt or atomized paint. Charge separation occurs at the orifice and. equal and opposite charges are produced on the orifice and on the particulate material. Any unearthed object in or near the cloud of particles can then acquire a charge from it. The charges on the orifice, if insulated from earth, and on other un-. earthed objects may be hazardous if a flammable mixture of any kind is present, and there may also be a risk of physiological shock to personnel.

To avoid these hazards the recommendations given in 37.2 to 37.6 should be followed,

37.2 Deliberate Release of Compressed Gas

37.2.1 In processes where a gas containing particulate matter is deliberately released, as in compressed air grit blasting, the equipment itself and adjacent metal objects should be earthed. It should be ensured that personnel working in the area do not present an ignition risk (see 43.3.1).

37.2.2 Both processes should not be carried out in the presence of flammable gases or vapours until it has been established that incendive discharges do not occur from the particulate suspension.

37.3 Accidental Leakage of Compressed Gas

Hazardous charges may be produced when either flammable or non-flammable gases are released accidentally, if they carry liquid or solid particulate matter. Wherever a leak could occur the containing vessel or pipe and any adjacent conducting objects should be earthed if there is any possibility of the presence of a flammable atmosphere, due either to the leakage or to other causes. Earthing is also required if a charged object could be moved into an area where a flammable atmosphere is present. It should be ensured that personnel going into the area of such leaks, for example, to effect repairs, do not present an ignition risk (see 43.3.1).

37.4 Fire Extinguishers

37.4.1 Some types of pressurized fire extinguisher, particularly those using carbon dioxide, can generate highly charged clouds. If there is a fire this is of little importance. However, if such equipment is situated where 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 ascertained that flammable mixtures are absent from the area.

37.4.2 The use of hand-held extinguisher may cause charging of the operator if he is not earthed, with a consequent risk of minor physiological shock. Nozzles are being developed to minimize this risk.

37.5 Inerting

37.5.1 The precautionary inerting of vessels containing flammable gas mixtures or dust suspensions should be done only with gases that do not contain particulate matter and that do riot condense to a liquid or solid phase when released at high pressure, for example, clean dry nitrogen, unless it can be shown that a hazardous potential will not be reached,

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

37.5.3 Whatever substance is used for inerting, it is advisable to introduce it slowly through a large orifice, to minimize the pick-up of dirt and scale from the lines and to avoid raising dust or spray by direct impingement after the gas has entered the vessel.

37.6 Spraying of Paints and Powders

Recommendations for avoiding electrostatic hazards when using these processes are given in 25.

38 SPRAYING OF PAINTS AND POWDERS

38.1 General

The clouds of droplets or particles produced by paint or powder spraying are frequently high charged. Both the spraying equipment and any object within the range of the spray may become charged. There may then be a risk of physiological shock, and there will be an ignition hazard if the cloud of droplets or particles is flammable.

These problems are normally present with airless and electrostatic processes but the level of charging with air-atomized spraying equipment is usually not high enough to cause concern. However, if sparking or electric shocks are encountered, air-atomized equipment should be submitted to the same precautions as other types of spraying equipment. These precautions are given in 38.2 to 38.4.

It is emphasized that spraying operations often involve the production of flammable atmospheres and the prevention of electrostatic hazards should not be considered in isolation. Precautions against a wider range of hazards may be required.

38.2 Earthing

The spraying equipment and all metallic objects in the vincinity of a paint or powder cloud should be earthed (see 15). It should be ensured that personnel operating the equipment do not present an ignition risk (see 43.3.1).

It is very important to earth the object being sprayed and it should be remembered that deposits laid down during spraying may tend to destory the earth connection. This problem may be overcome by the design of jigs and/or by the provision of automatic earth checking devices.

38.3 Spraying of High Resistivity Objects

Objects made from high resistivity materials should not be sprayed with electrostatically charged paints. There is much less hazard with powder spraying but the degree of hazard should be checked.

38.4 Plastics Spray Cabinets

Spray cabinets of high resistivity materials should not be used in the spraying of flammable paints, and they should be used with powders only if it can be shown that there is no ignition risk. Cabinets of conductive material are acceptable with all types of spray, provided that they are earthed.

39 RIGID PLASTICS SHEETING, WALLS AND SCREENS

39.1 General

Rigid plastics sheeting for wall cladding, internal room screens, etc (referred to subsequently as sheeting), does not readily accumulate electrostatic charge in normal use. However, sheeting made from high resistivity materials can become charged by rubbing of the surface and by other generating processes, such as paint spraying or steam impingement. In such situations there is a possible ignition hazard if a flammable atmosphere is present. Generally, the items being considered form part of a building and severe restraints are then placed on the occurrence of flammable atmospheres.

To avoid these ignition hazards the recommendations given in 39.2 to 39.4 should be followed.

In the case of sheeting of high resistivity materials, precautions are considered in terms of the hazardous zones defined in 4.12.

39.2 Sheeting Made from Conductive Materials

There is no electrostatic ignition hazard in connection with sheeting made from conductive nonmetallic materials (see 12.3.2) provided that. it is earthed. The resistance between every point on the surface and earth should not exceed $10^8 \Omega$, as measured by the test procedure described in **16.**

39.3 Sheeting Made from High Resistivity Materials

39.3.1 In Zone 0 areas the use of sheeting made from high resistivity materials is not recommended.

39.3.2 In Zone 1 and Zone 2 areas such sheeting as acceptable provided that the charge generation from any source is small and gives rise to an acceptably low ignition risk, equivalent to that from Zone 2 electrical equipment. In many cases it will be obvious that no significant charge generation will occur. If there is any doubt it is recommended that expert advice should be sought before high resistivity sheeting is used in Zone 1 and Zone 2 areas.

39.3.3 In Zone 1 and Zone 2 areas any metallic component mounted on the sheeting should be earthed and precautions should be taken to see that isolated conducting areas are not produced by deposits on the surface, if it is considered that any of them could accumulate a dangerous level of charge.

39.4 Sheeting Incorporating Conducting Elements

39.4.1 The electrostatic hazard from high resistivity materials is minimized in some types of sheeting by the incorporation in them of a conducting grid or support (usually metallic) or a plastics laminate, throughout the area of the sheet (see 12.3.6).

39.4.2 The conducting element and any metallic components mounted on the sheeting should be earthed.

39.4.3 Although rubbing may generate sufficient charge on the surface to give an incendive discharge, the probability that this will occur in normal practice is low. Where processes with a very high rate of charge generation, such as electrostatic spraying, occur, this type of sheeting should not be. used if there is any possibility of the presence of a flammable atmosphere.

40 PROCESSING OF FLEXIBLE SHEET OR FILM MATERIALS

40.1 General

High resistivity sheet and film materials, including many papers, plastics and textiles, readily acquire electrostatic charge during manufacture and conversion processes. Mere contact with a metal roller generally leaves charge on the surface of the materials; the metal takes the complementary charge, which rapidly dissipates provided that the machiriery is properly earthed. The major problems caused by charges on sheets and films are ignitions of flammable atmospheres, physiological shock, handling difficulties, and dirt and dust attraction.

Examples of these problems are as follows:

a) Accumulation of charged material on wound-up reels, causing shocks to personnel at reel change.
b) Charging of unearthed metal parts by passage of film over guides and rollers, leading to spark discharges liable to ignite volatile solvents. Personnel may also become charged by induction as well as by charge transfer from the film material.
c) Disruption of stacking by mutual repulsion of charged sheets.
d) Clinging of thin films to metal rollers, etc.
e) Quality degradation by attraction of dirt and dust to charged surfaces during coating.

To avoid such problems the recommendations in 40.2 and 40.3 should be followed, as appropriate.

40.2 Earthing

40.2.1 All metallic parts of machinery should be earthed. If a flammable atmosphere may be present, non-metallic components, such as rollers conveying tapes and trays or containers for sheets and cut-offs, should be conductive and, where possible, should have a resistance to earth less than $10^6 \Omega$. Nevertheless, it should be noted that earthing of metal rollers does not prevent the charging of the high resistivity sheet or film itself.

40.2.2 It should be ensured that personnel working on or passing near the machinery do not present an ignition risk (see 43.3.1).

40.3 Control of Charge on the Material

40.3.1 The operating conditions of the machinery should be chosen to minimize electrostatic charging. Thus, excessive running speeds and, very importantly, sticking rollers should be avoided. Any friction between a sheet and its conveying and guiding system should be reduced by reducing the area of contact as much as possible, for example by using corrugated surfaces. The pressure between rollers of drive nips should be kept as low as is consistant with preventing any slip.

40.3.2 ***Hydrophylic materials,*** for example, **cellulosics,** including cotton and paper, should have the highest moisture content compatible with process efficiency.

40.3.3 It may be possible to increase the conductivity of some sheet or film materials by the use of antistatic additives. As most antistatic agents depend on water absorption to enhance their ionic conduction, low relative humidity should be avoided when they are employed. In some circumstances it may be acceptable to use a conducting composite (for example, containing carbon black), where conduction is independent of humidity.

40.3.4 High charges are often imparted to sheet or film materials either deliberately, for example, in electrostatic 'pinning' to enhance grip between the material and a roller or base plate, or as a side effect of an electrical process, for example, in electrical discharge ('corona') treatment which is commonly used to improve adhesion to plastics. It is then essential to neutralize these charges as soon as possible, and especially before the material passes forward to a printing or coating unit where any flammable solvent is used.

40.3.5 Neutralization of charge on the surface of sheet or film materials may be readily accomplished by means of a static eliminator bases on air ionization (see 12.3.4). The choice of eliminator depends mainly on the application concerned, but in many cases a simple passive type is all that is necessary to prevent incendive discharges taking place. Where a passive eliminator will not work, for example, in the confines, of metal machinery, a high voltage eliminator should be tried. For efficient working of any eliminator it is necessary to site the eliminator opposite 'free web' as far away from earthed metalwork as possible, so as not to detract from the self-field of the charge being neutralized to the eliminator. Performance is critically dependent on distance from the film: too far away and neutralization is incomplete, too near and overcompensation occurs. The final setting (usually in the range 10 mm to 50 mm) is best obtained with the aid of a field meter to test for charge left on the film. Eliminators should be used singly; it is neither necessary nor desirable to have eliminators facing both sides of the film which carries the charge. Special eliminators are available for fast production lines and for the changing geometry of stacking and reeling operations.

41 EXPLOSIVES MANUFACTURE, HANDLING AND STORAGE

41.1 General

For the purposes of this clause explosives are materials defined as such in the Explosives Act. Static electricity accumulated on insulated conductors or personnel may cause the ignition of explosives with possibly 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, pelletized, compacted, moulded or filled into metal or plastics containers. Before handling or processing explosives, consideration should be given to the specific recommendations given below, but in addition reference should be made to those clauses of this Code 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 of 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 not the minimum ignition energy test described in 15, which should never be used with explosives.

The three classes of explosives and the precautions that should be adopted for them are given in 41.2 to 41.4. There should be no deviation from them without taking expert advice. Specialized earthing techniques are used in the explosives industry for sensitive or very sensitive explosives, information may be obtained from the relevant Statutory Authority.

41.2 Comparatively Insensitive Explosives

41.2.1 These materials have a minimum spark energy for ignition greater than 450 m J and the first degree precautions given in 41.2.2 are sufficient when they are handled.

41.2.2 All large conducting objects, such as fixed plant and equipment and pneumatic systems, should be earthed. Where the earthing is by means of metallic conductors the resistance to earth should be less than 10 Ω. Conductive or antistatic non-metallic materials may also be used for earthing (*see* 15).

41.3 Very Sensitive Explosives

41.3.1 The minimum spark energy for ignition of these materials is up to and including 1 mJ and the full second degree precautions given in 41.3.2 to 41.3.7 are required.

41.3.2 All equipment, including movable and portable items, should be earthed. High resistivity materials should be rigorously excluded.

41.3.3 All personnel should be earthed by means of conducting floors and footwear (see 43). A personnel resistance monitor (see 17) should be installed at every entrance to any area where such footwear is required. When handling compositions having ignition energies of less than 100 mJ consideration should be given to the installation of personnel resistance monitors at the individual work stations.

41.3.4 Outer clothing should not be made from high resistivity materials. Clothing should in no circumstances be removed in the area where the explosive is being handled (see 44).

41.3.5 Metallic objects which could act as spark promoters should be avoided, for example, rings on personnel, conductive tools or wires.

41.3.6 The relative himidity of the atmosphere should not be less than 65 percent.

41.3.7 Care should be taken to prevent a number of small capacitances working together to give a much larger capacitance.

41.4 Sensitive Explosive

41.4.1 These are materials with senstiveness between those dealt with in 41.2 and 41.3, and have minimum spark energies for ignition greater than 1mJ and up to and including 450 mJ.

41.4.2 Depending on the properties of the particular explosive and the way in which it is handled, some relaxation of the full second degree than precautions given in 41.3 may be acceptable. Specialist advice should be sought to determine the level of precautions applicable to each specific case.

42 HANDLING OF ELECTRO-EXPLOSIVE DEVICES

42.1 General

Electra-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 senstitive to electrostatic energy in this latter configuration. The static electricity may accumulate on insulated personnel as a result of their movements, and personal and items of equipments may become charged during 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 42.2 to 42.5 and they should be observed at all times when electro-explosive devices are being handled, that is, during storage, issue and use.

It should be recognized that there are other sources of hazard when handling electro-explosive devices and appropriate manuals should be consulted for these, for example, the pick-up of energy from sources of electromagnetic radiation, testing for continuity of the firing circuit, and procedures for the custody of the exploder key or the exploder.

42.2 Earthing

42.2.1 Personnel should have an adequately conducting path to earth, for exampel, by wearing leather soled footwear, and preferably they should wear cotton type clothing. However, in some environments, for example, mines, continuous earthing of personnel may not be feasible, and it is recommended that the procedures in 42.3 and 42.4 should therefore always be followed.

42.2.2 All conducting 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.

42.2.3 If a granular type explosive is being loaded pneumatically into a bore hole, the loading equipment should be earthed. The hose should be semi-conductive and should be connected to earth. Specialized codes of practice exist on this subject and should be consulted.

42.3 Precautions During Storage and Issue

Electra-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 should 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, for example, polyethylene bags or polystyrene foam packs; the use of metallic or conducting packs and advised for this purpose and these may also provide some protection against any radio frequency hazard.

42.4 Precautions During Use

42.4.1 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.

42.4.2 A check should be made to see that the device leads are connected together. After connecting them if necessary (see 42.3), 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.

42.4.3 The operative should then make sure that he is earthed before he handles the metal case of the device prior to connecting it to the firing cable. This is to prevent a discharge from the metal case to the fusehead. The use of insulating or similar self-adhesive tapes near electro-explosive devices is not advisable and should be completely avoided near devices having no-fire energies less than 100 mJ. If used at all, the piece of tape should be removed from the reel before use. Under no circumstances should tape be wound from the reel in the proximity of these devices.

42.4.4 The charge may then be inserted into the bore hole. The device leads and the firing cable wires at the firing end should then be disconnected from earth and connected to each other so that the device is in series with the cable. During this process the operative automatically earths himself on touching the leads prior to disconnection. It is recommended that the device is connected to the firing cable at the firing end before it is inserted into the charge. The operative should earth himself immediately before handling the device case or its leads.

42.4.5 The operative should then retire to the other end of the firing cable. When he is ready to fire he should disconnect the cable leads at the exploder end from earth and connect them to the terminals of the exploder.

42.5 Precautions in Adverse Weather Conditions

Electra-explosive devices should not be used on the approach of and during thunderstorms or ‘during dust or dry sand storms.

43 EARTHING OF PERSONNEL

43.1 General

The human body has a low enough volume resistivity to act as a conductor and if insulated from earth it can accumulate electrostatic charge. The charge may be produced by contact electrification, for example, by walking across an insulating floor, or by touching charged equipment or materials. It may also arise by induction due to charge on the clothing or adjacent charged objects (*see* 14.1 j.

A troublesome consequence of the electrostatic potential on charged personnel is that it can be high enough to cause damage to electrostatic sensitive devices, such as semiconductors, when these are being handled or assembled.

A discharge from a charged person can occur on touching any metallic object and a shock may be felt which, although not physically harmful, can be unpleasant. Involuntary reaction, however, can lead to accidents. If a flammable mixture of any kind is present with an ignition energy less than about 100 mJ the discharge may cause ignition (see 14.2.1).

In many situations the resistance of the footwear and flooring is fortuitously low enough to provide adequate earthing. The precautions that should be applied, using special equipment and materials if necessary, are given in 43.2 to 43.5.

43.2 Precautions in the Absence of Flammable Mixtures

43.2.1 Uncomfortable shocks due to discharges from personnel may be avoided by wearing footwear and using flooring materials such that the total resistance between the body and earth is less than 5 x $10^9 \Omega$. Floors of bare concrete, wood or cork are likely to be satisfactory for this purpose, provided that they are kept clean and are not covered by an insulating floor covering. Where a risk of exposure to mains voltage cannot be excluded the resistance to earth should be not less than 5x $10^4 \Omega$.

43.2.2 Disconcerting shocks are experienced by individuals walking on highly insulating floor coverings, usually carpets. Such shocks can be avoided by increasing the conductivity of the floor covering.

43.3 Precautions in the Presence of Flammable Vapours and Powders

43.3.1 Where a person may come into contact with a flammable vapour or dust of minimum ignition energy up to and including 100 mJ, it is recommended that he be earthed. This can be achieved by the use of suitable antistatic or conducting footwear and floors. It is emphasized that conducting footwear should only be used where it is compatible with the substance being processed and in situations where there is no risk of exposure to dangerous electric shock in the event of apparatus becoming defective when operating at voltages of up to 250 V to earth.

43.3.2 The resistance of footwear may increase in use due to continuous flexing and it may decrease because of permeation of perspiration through or around the insole. Both antistatic and conductive footwear should be discarded if their resistance rises above $10^8 \Omega$. Where a risk of exposure to mains voltage cannot be excluded the footwear should be discarded if its resistance falls below $5 \times 10^4 \Omega$. The resistance of the footwear while being worn can be measured by means of a personnel resistance monitor of the type described in 17.

43.3.3 It is emphazised that conducting floors should only be installed where there is no danger of exposure to mains voltage. The flooring should not raise the total resistance between the person and earth above $10^8 \Omega$. Deposits of insulating contaminants on the floor, such as oil or high resistivity powder, should be removed. Where there is any doubt about the resistance between the person and earth it may be measured by means of a suitably modified personnel resistance monitor of the type described in 17.

43.3.4 If the flammable mixture is confined to a limitedarea, for example, near a vessel containing a flammable liquid, it may be sufficient to render only a small area of the floor conductive. One method is to provide an earthed metal plate for the person to stand on.

43.4 Precautions for Highly Sensitive Materials

43.4.1 In areas where materials, such as some explosives or oxygen enriched flammable mixtures, are present conducting footwear should be worn. It is emphasized that conducting footwear should be used only where there is no danger of exposure to mains voltage. The footwear should be discarded when its resistance rises above $10^6 \Omega$.

43.4.2 The flooring should not raise the total resistance between the person and earth above $10^6 \Omega$. The floor should be cleaned frequently to ensure the absence of insulating contaminants, such as oil or high resistivity powder. A regular check should be made on the resistance between the person and earth by means of a suitably modified personnel resistance monitor of the type described in 17.

43.5 The Handling of Electrostatic Sensitive Devices

The special precautions should be applied in the handling and assembly of electrostatic sensitive devices.

44 HAZARD8 FROM CLOTHING

44.1 General

Clothing on the body can readily acquire an electrostatic charge when, for example, it rubs or presses against an external surface. Also, if an outer garment is removed, charge may be produced on the remaining clothing and on the garment that has been removed. The charged clothing on the body induces a similar charge on the body which will remain for some time if the person is insulated from earth by the footwear or the floor. Discharges may occur between the body, or the clothing on the body, or the clothing removed from the body and any conductor with which they happen to make contact. The charge on the body can be eliminated by earthing (see 43) but in some circumstances charge can still remain on the clothing. Discharges from the clothing may be sufficient to cause ignitions and the voltage may be -high enough to damage electrostatic sensitive devices, such as semi-conductors, when they are being handled.

Precautions to avoid hazards due to the clothing are given in 44.2 to 44.6 which should be read in conjunction with 43.3.

44.2 Precautions with Materials with Minimum ignition Energies Greater than 0·2 mJ

Any garment, including those made from high resistivity materials, such as some synthetic fibres and coated fabrics, may be worn in the presence of mixtures in air of vapours, powders or dusts with minimum ignition energies greater than 0.2 mJ, provided that the resistance between the person and earth complies with the recommendations of 43.3.

44.3 Precautions for Highly Sensitive Flammable Materials

44.3.1 Where materials with the minimum ignition energies up to and including 0·2 mJ may be present, such as some explosives and oxygen enriched flammable mixtures, the resistance between the person and earth should comply with the recommendations of 43.4.

44.3.2 Garments should not be warn in these situations if their surface resistivity is greater than $5 \times 10^{10} \Omega$. Natural fibres, such as cotton, flex or linen, meet this requirement provided that the relative humidity is moderately high, say 65 percent or more, and the temperature is about 20°C. Many synthetic fibres and coated fabrics should be used only if they have been treated as described in 44.3.3 to reduce their surface resistivities below $5 \times 10^{10} \Omega$ There are special requirements for hospitals The surface resistivities of garment materials may be measured using the method given in 18 with specimens conditioned at the minimum relative humidity expected in the working environment.

44.3.3 The simplest and most widely used method of reducing the electrostatic charge on fabrics is to apply an antistatic finish which reduces the surface resistivity. Some of these finishes are effective on a range of different fibres, while others are specific to only a few types of fibre. Most antistatic finishes function for only a limited period and they should, therefore, be applied at regular intervals, at least every time the garment is washed. Because the majority of them depend upon moisture from the atmosphere they are most effective in humid conditions.

44.3.4 Good antistatic properties can be achieved by introducing a small proportion of highly conducting fibres into fabrics. Such materials have the advantage over the antistatic finishes described in 44.3.3 that they are resistant to repeated washings and are effective in warm, dry conditions.

44.4 Removal of Clothing

Garments should not normally be removed in the presence of a flammable vapour/air mixture, powder or dust,

44.5 Gloves

When gloves satisfying other safety requirements are used for handling metallic or conductive objects in the presence of a flammable mixture of any kind, either the gloves should be of conductive or antistatic material or the objects should be earthed, for example, by means of an earthed clip lead. The resistance between each object and earth should not exceed $10^8 \Omega$ for mixtures in air of materials with minimum ignition energies greater than 0·2 mJ, and $10^6 \Omega$ for those with minimum ignition energies up to and including 0·2 mJ.

ANNEX A

(Foreword)

COMPOSITION OF ELECTRICAL INSTALLATIONS SECTIONAL COMMITTEE, ETDC 20

Chairman
Shri M. L. Dongre
M-3 Satyam, 88 Sion Circle, Bombay 400 022

Members	*Representing*
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Shri S. K. Shangari (*Alternate*)	
Shri P. D. Bagade	Tata Consulting Engineers, Bombay
Shri R. K. Kaul (Alternate)	
Shri V. S. Bhatia	Siemens India Ltd, Bombay
Shri M. M. Shethna (*Alternate*)	
Shri K. V. Chaubal	Federation of Electricity Undertaking of India, Bombay
Shri K. S. Joshi (Alternate)	
Shri R. R. Choudhuri	Larsen & Toubro (Construction Group), Madras
Shri N. Balasubramanian (*Alternate*)	
Chief Electrical Engineer	Railway Board (Ministry of Railways), New Delhi
Deputy Director Standards (Elec)-DI, RDSO (*Alternate*)	
Chief Electrical Inspector to Government of Tamil Nadu	Chief Electrical Inspector to Government of Tamil Nadu, Madras
Electrical Inspector (Technical) to Government of Tamil Nadu (*Alternate*)	
Chief Engineer (Elec)-I	Central Public Works Department, New Delhi
Superintendent Surveyor of Works (Elec)-I (*Alternate*)	
Shri Devender Nath	Larsen & Toubro Ltd, Bombay
Shri T.P. R. Sarma (*Alternate*)	
Shri K. W. Dharmadhikari	Jyoti Ltd, Vadodara
Dr V. N. Maller (*Alternate*)	
Shri G.L. Dua	Rural Electrification Corporation Ltd, New Delhi
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Er S. Paneerselvam	Tamil Nadu Electricity Board, Madras
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