

Chapter 3

STATIC ELECTRICITY

This Chapter describes hazards associated with the generation of static electricity during the loading and discharging of cargo and during tank cleaning, dipping, ullaging and sampling. Section 3.1 introduces some basic principles of electrostatics in order to explain how objects become charged and to describe the effect of those charges on other objects in close surroundings.

The risks presented by static electricity discharges occur where a flammable atmosphere is likely to be present. The main precaution for tankers against electrostatic risks is to conduct operations with the cargo tanks protected by inert gas. Section 3.2 describes, in general terms, precautions against electrostatic hazards in tanks that are not protected by inert gas; these are discussed in more detail in Chapter 11 (Shipboard Operations). Section 3.3 considers other likely sources of electrostatic hazards in tanker and terminal operations.

3.1 Principles of Electrostatics

3.1.1 Summary

Static electricity presents fire and explosion hazards during the handling of flammable liquids and during other tanker operations such as tank cleaning, dipping, ullaging and sampling. Certain operations can give rise to accumulations of electric charge that may be released suddenly in electrostatic discharges with sufficient energy to ignite flammable product gas/air mixtures. There is, of course, no risk of ignition unless a flammable mixture is present. There are three basic stages leading up to a potential electrostatic hazard:

- Charge separation.
- Charge accumulation.
- Electrostatic discharge.

All three of these stages are necessary for an electrostatic ignition of a flammable atmosphere.

Electrostatic discharges can occur as a result of accumulations of charge on:

- Liquid or solid non-conductors, for example a static accumulator oil (such as kerosene) pumped into a tank, or a polypropylene rope.
- Electrically insulated liquid or solid conductors, for example mists, sprays or particulate suspensions in air, or an unbonded metal rod hanging on the end of a rope.

The principles of electrostatic hazards and the precautions to be taken to manage the risks are described fully below.

3.1.2 Charge Separation

Whenever two dissimilar materials come into contact, charge separation occurs at the interface.

The interface may be between two solids, between a solid and a liquid or between two immiscible liquids. At the interface, a charge of one sign (say positive) moves from material A to material B so that materials A and B become respectively negatively and positively charged.

While the materials stay in contact and immobile relative to one another, the charges are extremely close together. The voltage difference between the charges of opposite sign is then very small, and no hazard exists. However, when the materials move relative to one another, the charges can be separated and the voltage difference increased.

The charges can be separated by many processes. For example:

- The flow of liquid product through pipes.
- Flow through fine filters (less than 150 microns) that have the ability to charge products to a very high level, as a result of all the product being brought into intimate contact with the filter surface where charge separation occurs.
- Contaminants, such as water droplets, rust or other particles, moving relative to product as a result of turbulence in the product as it flows through pipes.
- The settling of a solid or an immiscible liquid through a liquid (e.g. water, rust or other particles through the product). This process may continue for up to 30 minutes after completion of loading into a tank.
- Gas bubbles rising up through a liquid (e.g. air, inert gas introduced into a tank by the blowing of cargo lines or vapour from the liquid itself, released when pressure is dropped). This process may also continue for up to 30 minutes after completion of loading.
- Turbulence and splashing in the early stages of loading product into an empty tank. This is a problem in the liquid and in the mist that can form above the liquid.
- The ejection of particles or droplets from a nozzle (e.g. during steaming operations or injection of inert gas).
- The splashing or agitation of a liquid against a solid surface (e.g. water washing operations or the initial stages of filling a tank with product).
- The vigorous rubbing together and subsequent separation of certain synthetic polymers (e.g. the sliding of a polypropylene rope through gloved hands).

When the charges are separated, a large voltage difference can develop between them. A voltage distribution is also set up throughout the neighbouring space and this is known as an electrostatic field. Examples of this are:

- The charge on a charged liquid in a tank produces an electrostatic field throughout the tank, both in the liquid and in the ullage space.
- The charge on a water mist formed by tank washing produces an electrostatic field throughout the tank.

If an uncharged conductor is present in an electrostatic field, it has approximately the same voltage as the region it occupies. Furthermore, the field causes a movement of charge within the conductor; a charge of one sign is attracted by the field to one end of the conductor and an equal charge of the opposite sign is left at the opposite end. Charges separated in this way are known as 'induced charges' and, as long as they are kept separate by the presence of the field, they are capable of contributing to an electrostatic discharge.

3.1.3 Charge Accumulation

Charges that have been separated attempt to recombine and to neutralise each other. This process is known as 'charge relaxation'. If one or both of the separated materials carrying charge is a very poor electrical conductor, recombination is impeded and the material retains or accumulates the charge upon it. The period of time for which the charge is retained is characterised by the relaxation time of the material, which is related to its conductivity; the lower the conductivity, the greater the relaxation time.

If a material has a comparatively high conductivity, the recombination of charges is very rapid and can counteract the separation process, and consequently little or no static electricity accumulates on the material. Such a highly conductive material can only retain or accumulate charge if it is insulated by means of a poor conductor, and the rate of loss of charge is then dependent upon the relaxation time of this lesser conducting material.

The important factors governing relaxation are therefore the electrical conductivities of the separated materials, of other conductors nearby, such as tanker's structure, and of any additional materials that may be interposed between them after their separation.

3.1.4 Electrostatic Discharge

Electrostatic discharge occurs when the electrostatic field becomes too strong and the electrical resistance of an insulating material suddenly breaks down. When breakdown occurs, the gradual flow and charge recombination associated with relaxation is replaced by sudden flow recombination that generates intense local heating (e.g. a spark) that can be a source of ignition if it occurs in a flammable atmosphere. Although all insulating media can be affected by breakdowns and electrostatic discharges, the main concern for tanker operations is the prevention of discharges in air or vapour, so as to avoid sources of ignition.

Electrostatic fields in tanks or compartments are not uniform because of tank shape and the presence of conductive internal protrusions, such as probes and structure. The field strength is enhanced around these protrusions and, consequently, that is where discharges generally occur. A discharge may occur between a protrusion and an insulated conductor or solely between a conductive protrusion and the space in its vicinity, without reaching another object.

3.1.4.1 Types of Discharge

Electrostatic discharge can take the form of a 'corona', a 'brush discharge', a 'spark' or a 'propagating brush discharge', as described below:

Corona is a diffuse discharge from a single sharp conductor that slowly releases some of the available energy. Generally, corona on its own is incapable of igniting a gas.

Brush Discharge is a diffuse discharge from a highly charged non-conductive object to a single blunt conductor that is more rapid than corona and releases more energy. It is possible for a brush discharge to ignite gases and vapours. Examples of a brush discharge are:

- Between a conductive sampling apparatus lowered into a tank and the surface of a charged liquid.
- Between a conductive protrusion (e.g. fixed tank washing machine) or structural member and a charged liquid being loaded at a high rate.

Spark is an almost instantaneous discharge between two conductors where almost all of the energy in the electrostatic field is converted into heat that is available to ignite a flammable atmosphere. Examples of sparks are:

- Between an unearthed conductive object floating on the surface of a charged liquid and the adjacent tank structure.
- Between unearthed conductive equipment suspended in a tank and the adjacent tank structure.
- Between conductive tools or materials left behind after maintenance when insulated by a rag or piece of lagging.

Sparks can be incendive if various requirements are met. These include:

- A discharge gap short enough to allow the discharge to take place with the voltage difference present, but not so short that any resulting flame is quenched.
- Sufficient electrical energy to supply the minimum amount of energy to initiate combustion.

Propagating Brush Discharge is a rapid, high energy discharge from a sheet of material of high resistivity and high dielectric strength with the two surfaces highly charged but of opposite polarity. The discharge is initiated by an electrical connection (short circuit) between the two surfaces. The bipolar sheet can be in 'free space' or, as is more normal, have one surface in intimate contact with a conducting material (normally earthed).

The short circuit can be achieved:

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

A propagating brush discharge can be highly energetic (1 joule or more) and so will readily ignite a flammable mixture.

Scientific studies have shown that epoxy coatings greater than 2 mm thick on tanks, filling pipes and fittings may give rise to conditions whereby there is a possibility of a propagating brush discharge. In these cases, there would be a need to seek expert advice on requirements to explicitly earth the cargo. However, on most tankers, the thickness of epoxy coatings is not generally greater than 2 mm.

3.1.4.2 Conductivity

Materials and liquid products that are handled by tankers and terminals are classified as being non-conductive, semi-conductive (in most electrostatic standards the term 'dissipative' is now preferred to 'semi-conductive') or conductive.

Non-Conductive Materials (or Non-Conductors)

These materials have such low conductivities that once they have received a charge they retain it for a very long period. Non-conductors can prevent the loss of charge from conductors by acting as insulators. Charged non-conductors are of concern because they can generate incendive brush discharges to nearby earthed conductors and because they can transfer a charge to, or induce a charge on, neighbouring insulated conductors that may then give rise to sparks.

Liquids are considered to be non-conductors when they have conductivities less than 50 pS/m (pico Siemens/metre). Such liquids are often referred to as static accumulators. Reference should be made to a product's (M)SDS to ascertain its conductivity.

The solid non-conductors include plastics, such as polypropylene, PVC, nylon and many types of rubber. They can become more conductive if their surfaces are contaminated with dirt or moisture. (Precautions to be taken when loading static accumulator oils are addressed in Section 11.1.7.)

Semi-Conductive Materials (or Dissipative Materials or Intermediate Conductors)

The liquids in this intermediate category have conductivities exceeding 50pS/m and, along with conductive liquids, are often known as static non-accumulators. The solids in this intermediate category generally include such materials as wood, cork, sisal and naturally occurring organic substances. They owe their conductivity to their ready absorption of water and they become more conductive as their surfaces are contaminated by moisture and dirt. However, when new or thoroughly cleaned and dried, their conductivities can be sufficiently low to bring them into the non-conductive range.

If materials in the intermediate conductivity group are not insulated from earth, their conductivities are high enough to prevent accumulation of an electrostatic charge. However, their conductivities are normally low enough to inhibit production of energetic sparks.

For materials with intermediate conductivities, the risk of electrostatic discharge is small, particularly if practices in this Guide are adhered to, and the chance of their being incendive is even smaller. However, caution should still be exercised when dealing with intermediate conductors because their conductivities are dependent upon many factors and their actual conductivity is not known.

Conductive Materials

In the case of solids, these are metals and, in the case of liquids, the whole range of aqueous solutions, including sea water. The human body, consisting of about 60% water, is effectively a liquid conductor. Many alcohols are conductive liquids.

The important property of conductors is that they are incapable of holding a charge unless insulated, but also that, if they are insulated, charged and an opportunity for an electrical discharge occurs, all the charge available is almost instantaneously released into the potentially incendive discharge.

Table 3.1 provides information on the typical conductivity value and classification for a range of products:

Product	Typical Conductivity (picoSiemens/metre)	Classification
Non-Conductive		
Xylene	0.1	Accumulator
Gasoline (straight run)	0.1 to 1	Accumulator
Diesel (ultra-low sulphur)	0.1 to 2	Accumulator
Lube oil (base)	0.1 to 1,000*	Accumulator
Commercial jet fuel	0.2 to 50	Accumulator
Toluene	1	Accumulator
Kerosene	1 to 50	Accumulator
Diesel	1 to 100*	Accumulator
Cyclohexane	<2	Accumulator
Motor gasoline	10 to 300*	Accumulator
Semi-Conductive		
Fuel with anti-static additive	50 to 300	Non-accumulator
Heavy black fuel oils	50 to 1,000	Non-accumulator
Conductive crude	>1,000	Non-accumulator
Bitumen	>1,000	Non-accumulator
Alcohols	100,000	Non-accumulator
Ketones	100,000	Non-accumulator
Conductive		
Distilled water	1,000,000,000	Non-accumulator
Water	100,000,000,000	Non-accumulator

Table 3.1 - Typical conductivity of products

3.1.5 Electrostatic Properties of Gases and Mists

Under normal conditions, gases are highly insulating and this has important implications with respect to mists and particulate suspensions in air and other gases. Charged mists are formed during the ejection of liquid from a nozzle, for example:

- Products entering an empty tank at high velocity.
- Wet steam condensing.
- Water from tank washing machines.

Although the liquid, for example water, may have a very high conductivity, the relaxation of the charge on the droplets is hindered by the insulating properties of the surrounding gas. Fine particles present in inert flue gas, or created during discharge of pressurised liquid carbon dioxide, are frequently charged. The gradual charge relaxation, which does occur, is the result of the settling of the particles or droplets and, if the field strength is high, of corona discharge at sharp protrusions. Under certain circumstances, discharges with sufficient energy to ignite product gas/air mixtures can occur. See also Section 3.3.4.

3.2 General Precautions Against Electrostatic Hazards

3.2.1 Overview

Whenever a flammable atmosphere could potentially be present, the following measures must be taken to prevent electrostatic hazards:

- The bonding of metal objects to the metal structure of the tanker to eliminate the risk of spark discharges between metal objects that might be electrically insulated. This includes metallic components of any equipment used for dipping, ullaging and sampling.
- The removal from tanks or other hazardous areas of any loose conductive objects that cannot be bonded.
- Restricting the linear velocity of the cargo to a maximum of 1 metre per second at the individual tank inlets during the initial stages of loading, i.e. until:
 - a) the filling pipe and any other structure on the base of the tank has been submerged to twice the filling pipe diameter in order that all splashing and surface turbulence has ceased and
 - b) any water collected in the pipeline has been cleared. It is necessary to load at this restricted rate for a period of 30 minutes or until two pipeline volumes (i.e. from shore tank to ship's tank) have been loaded into the tank, whichever is the lesser.

Diameter	Number of tanks open – velocity in m ³ /h							
	1	2	3	4	5	6	7	8
6" / 150 mm	65	130	200	260	325	390	450	520
8" / 200 mm	120	240	350	460	580	700	820	-
10" / 250 mm	180	360	540	720	910	-	-	-
12" / 300 mm	260	520	780	-	-	-	-	-

Table 3.2 – Loading Rates Equivalent to Flow Velocity of 1 metre/second (Initial Stage of Loading)
Also see chapter 7.3.3.2 and 11.1.7.3

- Continuing to restrict the product flow to a maximum of 1 m/s at the tank inlet for the whole operation unless the product is 'clean'. A 'clean' product, within this context, is defined as one which contains less than 0.5% by volume of free water or other immiscible liquid and less than 10 mg/l of suspended solids¹.
- Avoiding splash filling by employing bottom entry using a fill pipe terminating close to the bottom of the tank.

The following additional precautions should be taken against static electricity during ullaging, dipping, gauging or sampling of static accumulator products:

- Banning the use of all metallic equipment for dipping, ullaging and sampling during loading and for 30 minutes after completion of loading. After the 30 minute waiting period, metallic equipment may be used for dipping, ullaging and sampling, but it must be effectively bonded and securely earthed to the structure of the tanker before it is introduced into the tank, and must remain earthed until after removal.
- Banning the use of all non-metallic containers of more than 1 litre capacity for dipping, ullaging and sampling during loading and for 30 minutes after completion of loading.

Non-metallic containers of less than 1 litre capacity may be used for sampling in tanks at any time, provided that they have no conducting components and that they are not rubbed prior to sampling. Cleaning with a high conductivity proprietary cleaner, a solvent such as 70:30 IPA:toluene mix, or soapy water, is recommended to reduce charge generation. To prevent charging, the container should not be rubbed dry after washing.

¹ CENELEC Technical Report CLC/TR 50404, "Electrostatics - Code of Practice for the Avoidance of Hazards Due to Static Electricity, June 2003.

Operations carried out through a correctly designed and installed sounding pipe are permissible at any time. It is not possible for any significant charge to accumulate on the surface of the liquid within the sounding pipe and therefore no waiting time is required. However, the precautions to be observed against introducing charged objects into a tank still apply and if metallic equipment is used it should be bonded before being inserted into the sounding pipe.

Detailed guidance on precautions to be taken during ullaging, dipping and sampling of static accumulator oils is given in Section 11.8.2.3. These precautions should be rigidly adhered to in order to avoid hazards associated with the accumulation of an electrical charge on the cargo.

3.2.2 Bonding

The most important countermeasure that must be taken to prevent an electrostatic hazard is to bond all metallic objects together to eliminate the risk of discharges between objects that might be charged and electrically insulated. To avoid discharges from conductors to earth, it is normal practice to include bonding to earth ('earthing' or 'grounding'). On tankers, bonding to earth is effectively accomplished by connecting metallic objects to the metal structure of the tanker, which is naturally earthed through the water.

Some examples of objects which might be electrically insulated in hazardous situations and which must therefore be bonded are:

- Ship/shore hose couplings and flanges, except for the insulating flange or single length of non-conducting hose required to provide electrical isolation between the ship and shore. (See Section 17.5.)
- Portable tank washing machines.
- Manual ullaging and sampling equipment with conducting components.
- The float of a permanently fitted ullaging device if its design does not provide an earthing path through the metal tape.

The best method of ensuring bonding and earthing will usually be a metallic connection between the conductors. Alternative means of bonding are available and have proved effective in some applications, for example semi-conductive (dissipative) pipes and 'O' rings, rather than embedded metallic layers, for GRP pipes and their metal couplings.

Any earthing or bonding links used as a safeguard against the hazards of static electricity associated with portable equipment must be connected whenever the equipment is set up and not disconnected until after the equipment is no longer in use.

3.2.3 Avoiding Loose Conductive Objects

Certain objects may be insulated during tanker operations, for example:

- A metal object, such as a can, floating in a static accumulating liquid.
- A loose metal object while it is falling in a tank during washing operations.
- A metallic tool, lying on a piece of old lagging, left behind after maintenance.

Every effort should be made to ensure that such objects are removed from the tank since there is evidently no possibility of deliberately bonding them. This necessitates careful inspection of tanks, particularly after shipyard repairs.

3.3 Other Sources of Electrostatic Hazards

3.3.1 Filters

Three classifications of filter may be used as follows:

Coarse (greater than or equal to 150 microns).

These do not generate a significant amount of charge, and require no additional precautions provided that they are kept clean.

Fine (less than 150 microns, greater than 30 microns).

These can generate a significant amount of charge and therefore require sufficient time for the charge to relax before the liquid reaches the tank. It is essential that the liquid spends a minimum of 30 seconds (residence time) in the piping downstream of the filter. Flow velocity should be controlled to ensure that this residence time requirement is met.

Microfine (less than or equal to 30 microns).

To allow sufficient time for the charge to relax, the residence time after passing through microfine filters must be a minimum of 100 seconds before the product enters the tank. Flow velocity should be adjusted accordingly

3.3.2 Fixed Equipment in Cargo Tanks

A metal probe, remote from any other tank structure but near a highly charged liquid surface, will have a strong electrostatic field at the probe tip. Protrusions of this type may be associated with equipment mounted from the top of a tank, such as fixed washing machines or high level alarms. During the loading of static accumulator oils, this strong electrostatic field may cause electrostatic discharges to the approaching liquid surface.

Metal probes of the type described above can be avoided by installing the equipment adjacent to a bulkhead or other tank structure to reduce the electrostatic field at the probe tip. Alternatively, a support can be added running from the lower end of the probe downward to the tank structure below, so that the rising liquid meets the support at earth potential rather than the insulated tip of a probe. Another possible solution, in some cases, is to construct the probe-like device entirely of a non-conductive material. These measures are not necessary if the tanker is limited to conductive products or if the tanks are inerted.

3.3.3 Free Fall in Tanks

Loading or ballasting over the top (overall) delivers charged liquid to a tank in such a manner that it can break up into small droplets and splash into the tank. This may produce a charged mist as well as an increase in the product gas concentration in the tank. Restrictions upon loading or ballasting overall are given in Section 11.1.12.

3.3.4 Water Mists

The spraying of water into tanks, for instance during water washing, gives rise to electrostatically charged mist. This mist is uniformly spread throughout the tank being washed.

The electrostatic levels vary widely from tank to tank, both in magnitude and in sign.

When washing is started in a dirty tank, the charge in the mist is initially negative, reaches a maximum negative value, then goes back through zero and finally rises towards a positive equilibrium value. It has been found that, among the many variables affecting the level and polarity of charging, the characteristics of the wash water and the degree of cleanliness of the tank have the most significant influence. The electrostatic charging characteristics of the water are altered by re-circulation or by the addition of tank cleaning chemicals, either of which may cause very high electrostatic potentials in the mist. Potentials are higher in large tanks than in small ones. The size and number of washing machines in a tank affect the rate of change of charge, but they have little effect on the final equilibrium value.

The charged mist droplets created in the tank during washing give rise to an electrostatic field, which is characterised by a distribution of potential (voltage) throughout the tank space. The bulkheads and structure are at earth (zero) potential and the space potential increases with distance from these surfaces and is highest at points furthest from them. The field strength, or voltage gradient, in the space is greatest near the tank bulkheads and structure, more especially where there are protrusions into the tank. If the field strength is high enough, electric breakdown occurs into the space, giving rise to a corona. Because protrusions cause concentrations of field strength, a corona occurs preferentially from such points. A corona injects a charge of the opposite sign into the mist and is believed to be one of the main processes limiting the amount of charge in the mist to an equilibrium value. The corona discharges produced during tank washing are not strong enough to ignite the hydrocarbon gas/air mixtures that may be present.

Under certain circumstances, discharges with sufficient energy to ignite product gas/air mixtures can occur from unearthed conducting objects already within, or introduced into, a tank filled with charged mist. Examples of such unearthed conductors are a metal sounding rod suspended on a rope or a piece of metal falling through the tank space.

An unearthed conductor within a tank can acquire a high potential, primarily by induction, when it comes near an earthed object or structure, particularly if the latter is in the form of a protrusion. The unearthed conductor may then discharge to earth giving rise to a spark capable of igniting a flammable product gas/air mixture.

The processes by which unearthed conductors give rise to ignitions in a mist are fairly complex, and a number of conditions must be satisfied simultaneously before an ignition can occur.

These conditions include the size of the object, its trajectory, the electrostatic level in the tank and the geometrical configuration where the discharge takes place.

As well as solid unearthed conducting objects, an isolated slug of water produced by the washing process may similarly act as a spark promoter and cause an ignition. Experiments have shown that high capacity, single nozzle, fixed washing machines can produce water slugs which, owing to their size, trajectory and duration before breaking up, may satisfy the criteria for producing incendive discharges. However, there is no evidence of water slugs capable of producing incendive discharges being produced by portable types of washing machine. This can be explained by the fact that, if the jet is initially fine, the length of slugs that are produced are relatively small so that they have a small capacitance and do not readily produce incendive discharges.

Following extensive experimental investigations and using the results of long-term experience, the tanker industry has drawn up the tank washing guidelines set out in Section 11.3. These guidelines are aimed at preventing excessive charge generation in mists and at controlling the introduction of unearthed conducting objects when there is charged mist in the tank.

3.3.5 Inert Gas

Small particulate matter carried in inert gas can be electrostatically charged. The charge separation originates in the combustion process and the charged particles are capable of being carried through the scrubber, fan and distribution pipes into the cargo tanks. The electrostatic charge carried by the inert gas is usually small, but levels of charge have been observed well above those encountered with the water mists formed during washing. Because the tanks are normally in an inert condition, the possibility of an electrostatic ignition has to be considered only if it is necessary to inert a tank which already contains a flammable atmosphere or if a tank already inerted is likely to become flammable because the oxygen content rises as a result of ingress of air. Precautions are then required during dipping, ullaging and sampling. (See Section 11.8.3.)

3.3.6 Discharge of Carbon Dioxide

During the discharge of pressurised liquid carbon dioxide, the rapid cooling which takes place can result in the formation of particles of solid carbon dioxide that become charged on impact and contact with the nozzle. The charge can be significant with the potential for incendive sparks. Liquefied carbon dioxide should not be used for inerting, or injected for any other reason into cargo tanks or pump rooms that may contain flammable gas mixtures.

3.3.7 Clothing and Footwear

People who are insulated from earth by their footwear or the surface on which they are standing can become electrostatically charged. This charge can arise from physical separation of insulating materials caused, for instance, by walking on a very dry insulating surface (separation between the soles of the shoes and the surface) or by removing a garment.

3.3.8 Synthetic Materials

An increasing number of items manufactured from synthetic materials are being offered for use on board tankers. It is important that those responsible for their provision to tankers should be satisfied that, if they are to be used in flammable atmospheres, they will not introduce electrostatic hazards.

