

SAFE WORKING WITH INDUSTRIAL SOLVENTS

Flammability: A safety guide for users

Best Practice Guidelines N°

4



EUROPEAN SOLVENTS INDUSTRY GROUP

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FOREWORD

Flammability is one of the main hazards associated with industrial solvents. This three-part document has been developed by the European Solvents Industry Group (ESIG) to explain the main characteristics of solvent flammability, and to provide recommendations for safe use. The important aspect of static electricity is covered in detail.

The first part of the document is a summary of the key recommendations that should be borne in mind when handling flammable products.

The second part of the document is targeted at readers who wish to have a more in-depth understanding of the product characteristics related to flammability.

The third part of the document deals specifically with static electricity and contains a section with requirements to be fulfilled during typical solvent handling operations.

The recommendations provided in this document are necessarily of a general nature, and cannot cover specific solvents or specific applications. Users are responsible for making their own analysis based on their own solvent usage, and should reach their own conclusions based on all data and information available to them.

ESIG has used its best efforts and knowledge to compile the information contained within this article. The reader's assessment and/or use of such information are the responsibility of the reader: ESIG declines any responsibility or liability for any use to which the information may be put.

PART 1 Key recommendations for handling flammable solvents

1.1 INTRODUCTION

Solvents are recognised as essential in many industries today and their use is widespread. Solvents provide key properties for use in manufacturing paints, adhesives, inks, plastics, surface coatings and many other process applications. However, many solvents are considered hazardous because they have relatively low boiling points. A low boiling point is a desired property in many applications in which solvents are used, because the solvent must evaporate in order to leave behind the required film of coating, or of adhesive. But the fact that solvents may have a low boiling point may mean that they produce vapours at ambient temperatures which can ignite if the storage and process conditions are not suitably controlled. The control process is known as "managing risk" and successful control systems help to minimise unnecessary releases to the atmosphere that could lead to fire or explosion.

The workplace can be made safer by following these "top ten tips" for handling solvents.

- 1 — Understand the solvent(s) you are using and its (their) properties. This is readily seen from your suppliers' SDS (Safety Data Sheet) which must be supplied to you for each product you use.
- 2 — Eliminate ignition sources e.g. No smoking, Safe Systems of Work, equipment selection, minimise static build up by using suitable equipment and earthing arrangements.
- 3 — Ensure good ventilation by working in open atmospheres (e.g. keep doors and windows open) or by using forced ventilation.
- 4 — Work at ambient temperatures.
- 5 — Provide information, instruction and training to all persons handling solvents.
- 6 — Report all incidents e.g. leaks and provide clean-up and disposal facilities.
- 7 — Provide secondary containment solutions such as bunding or oversize drums.
- 8 — Take special precautions when loading or unloading vehicles and containers.
- 9 — Develop a short, succinct Emergency Plan.
- 10 — Consider inert storage solutions such as nitrogen blankets.

To develop this theme further ESIG has identified a number of key recommendations common to most solvents. A broad understanding of the properties that make solvents hazardous and how these properties can influence everyday operations should ensure that users can quickly develop a high level of knowledge and understanding of how to make the workplace more safe. Information regarding the key recommendations listed below can be found in suppliers' Safety Data Sheets for specific solvents. Further detailed explanations of the particular characteristics can be found in Part 2 of this guide. These general recommendations are not a substitute for understanding the specific characteristics of the solvent(s) that you use.

1.2 KEY RECOMMENDATIONS

- Operators must be trained to understand the characteristics of, and safe handling methods for, the specific solvents in use in their workplace.
- Read the material-specific safety data sheets, which must be made available by suppliers.
- The occurrence of flammable solvent vapours can be estimated from the flash point and the limits of flammability.
 - A low flash point (< 55°C) indicates a more hazardous material and the need for more care in handling.
 - Note that there is no link between LELs (Lower Explosion Limits) and OELs (Occupational Exposure Limits).
- The Auto Ignition temperature (AIT) is a very rough guide to the maximum temperature that a mixture of a flammable solvent in air can reach before self-ignition. A significant safety margin must be kept between the measured AIT and the operating temperature.
 - There is no link between AIT and flash point.
- Droplet mists of solvents can be flammable at temperatures well below the flash point of the liquid. In situations where mists and sprays cannot be avoided, specific safety measures must be taken. Consult a specialist.
- There is a wide range of sources capable of igniting mixtures of flammable solvent vapours in air.
 - Most sources of ignition encountered in industrial facilities can ignite a flammable solvent vapour/air mixture (examples: spark of a calculator, mobile phone, metal tool falling on the floor).
 - The least obvious source of ignition and the most common source of incidents is static electricity.

Hydrocarbon solvents are particularly good static electricity accumulators. Working with hydrocarbon solvents may pose more of a hazard than oxygenated solvents, because they can in their own right accumulate static electricity which may cause sparking and subsequent fire.

- Keep solvent vapours below the Lower Explosion Limit (LEL) by:
 - Working at least 15 to 20°C below the flash point wherever possible.
 - Ensuring adequate ventilation: Vapours should be diluted to a level of < 25 % of the LEL (Lower Explosion Limit) value to ensure safe operation. The easiest way to assure ventilation, where it is possible, is by opening doors and windows. In many cases, mechanical ventilation is necessary. Ventilation is even more important when working above flash point cannot be avoided. The ventilation exhaust should be at least 3 m above the ground level and 3 m from building openings. 6 complete air changes/hour should be provided. A detector should be used in the ducts, linked to an alarm, in case of a possible extraction system failure.
 - Applying basic housekeeping practices: prevent unnecessary vapours by using the right amount of solvent required, and not more, by keeping lids on containers, and by using sealed containers for solvent contaminated waste. Do not leave solvent impregnated rags lying around.
- Eliminate oxygen:
 - Use inert gas (e.g. nitrogen blanketing) to remove oxygen from the system, in particular if ignition sources cannot be totally eliminated or if hot spots cannot be avoided.
- Eliminate sources of ignition:
 - Do not smoke, weld, or use naked lights in any area that may contain solvent vapours.
 - Work permit procedures must be followed scrupulously.
 - Use explosion-proof equipment.
 - Eliminate hot spots.
 - Minimise the risk of static electricity build-up as explained in Part 3:
 - Earth and bond equipment
 - Check earth resistance: it should be less than 10 ohms
 - No splash filling
 - Limit pipe velocity
 - Wait to allow dissipation of charges
 - Use conductive hoses
 - If a filter is used during filling operations, longer relaxation or dissipation times may be required
 - Switch loading can be very dangerous if compartments have not been gas-free
 - Do not fill hydrocarbons with flashpoints of <40°C into plastic containers
 - Avoid the use of compressed air for the line clearance of flammable products
 - Wear antistatic protective clothing and footwear
- When working in confined spaces is unavoidable, a company-approved safe system of work must be implemented with adequate emergency arrangements, including evacuation procedures.
- Bear in mind that solvent vapours are heavier than air and settle in low areas such as drains.
- Report fault and incidents, including minor spills or leaks. The subsequent evaluation of these reports by company management should help eliminate future occurrences!

- Have emergency procedures in place for dealing with fires, spills or leaks that cover the following:
 - Raising the alarm
 - Calling the Fire Brigade
 - Tackling the fire or leak using suitable fire fighting equipment for controlling a spill if it is safe to do so in line with defined procedures
 - Shutting down the plant in a safe way
 - Evacuating the plant safely
- Consult a specialist in case of doubt

Each year there are incidents involving solvents. ESIG has evaluated the root causes of incidents in the workplace and, most frequently a lack of understanding of the nature of the solvents used, and their hazards, is at the heart of the problem. Common incident causes are identified below.

- Lack of training, meaning insufficient Manager/Supervisor/Operator understanding, awareness and competence
- Poor control of solvent use in hot areas
- Badly designed equipment or installation, leading to unnecessary emissions or even leaks
- Poor selection of equipment (not suited to job)
- Equipment failure
- Poorly managed maintenance activities (especially in dismantling or disposal)
- Low understanding of the importance of safeguarding against electrostatic discharges
- Poor implementation of control procedures such as elimination of ignition sources
- Heating solvents without adequate controls
- Badly managed transfer operations such as filling and emptying equipment
- Loading and unloading of solvents without taking adequate precautions

PART 2 Technical aspects of flammability

2.1 INTRODUCTION

This section of the Guide for User's considers the technical characteristics of solvents and how these characteristics might make solvents hazardous. The guide covers:

- Flammability
- Flash Point
- Auto Ignition Temperatures (AIT)
- Solvent Mists
- Minimum Ignition Energy
- Sources of Ignition

2.1.1 Flammability range

Three components must be present for a fire or an explosion to occur: combustible vapours (in the present context, solvent vapours), an oxidiser (usually oxygen from the air) and a source of ignition. A number of parameters are commonly used to characterise the flammability properties of a product.

- Flammable liquids must evaporate into the air from the liquid before they can burn, and this is dependent upon temperature.
- The flammability (explosive) limits of the substance.

When the vapour of a flammable liquid is mixed with air in certain concentrations, and in the presence of a source of ignition, a rapid combustion or an explosion can occur.

This specific vapour/air concentration is called the "flammable range" and might also be referred to as the explosive range. In the flammable range, a flash will occur or a flame will spread if the mixture is ignited. The borders of the flammable range are called **Lower Explosion Limit (LEL)** and **Upper Explosion Limit (UEL)**.

The lower explosion limit (LEL) is the lowest concentration of vapour in air at which the vapour /air mixture is flammable.

The upper explosion limit (UEL) is the highest concentration of vapour in air at which the vapour /air mixture is flammable.

LEL/UEL are usually expressed in terms of percentage by volume of vapour in air. Below the LEL it is said the mixture is too lean to burn and above the UEL, the mixture is too rich to burn.

LEL and UEL data are based upon normal atmospheric temperatures and pressures (20°C) unless otherwise specified. These values are indicated in the suppliers' Safety Data Sheets (section 9). Flammable limits can significantly vary with pressure or temperature. The general effect of increasing the temperature is to lower the LEL and to raise the UEL.

If you do not work at ambient temperature, remember that the flammable range is broader than at room temperature.

It should be noted that many LELs and UELs are theoretical calculations and as such should be regarded as guide values only. The aim in practice should be to prevent vapour formation.

NB: Under certain conditions cool flames may occur in the region regarded as over rich (above UEL). Such flames are mildly exothermic; as a general rule a controlled temperature, of about 300-400°C is to be applied for their initiation. Though this should not lead to an explosive combustion, it should be taken into account when examining potential sources of ignition in a system.

Substance	Closed Cup Flash Point °C	Lower Explosive Limit % v/v	Upper Explosive Limit % v/v	Auto-ignition Temperature °C
Benzene	-11	1.4	7.1	560
n-Heptane	-4	1.2	6.7	215
n-Hexane	-22	1.2	7.5	233
n-Nonane	31	0.74	2.9	205
Iso Octane	-12	1.1	6.0	411
n-Octane	13	1.0	3.2	210
Light dearomatised hydrocarbon fraction (100-140°C boiling range)	1	0.8	8.0	
Dearomatised white spirit (150-200°C boiling range)	39-41*	0.6	6.5	
White spirit (150-200°C boiling range)	38-40*	0.8	6.5	
Toluene	4	1.3	7.0	535
Pentane	-49	1.5	7.8	285
m-Xylene	25	1.1	7.0	525
Aromatic solvent (160-185°C boiling range)	47-50*	1.0	7.5	
Acetone	-18	2.6	12.8	485
Methyl Ethyl Ketone	-7	1.8	11.5	505
Methanol	10	7.3	36	455
Ethanol	13	3.3	19	365
n-Butanol	35	1.4	11.2	340
iso Propanol	12	2.0	12.0	425
Ethyl Acetate	-4	2.2	11.4	460
n-Butyl Acetate	24	1.7	15.0	370

* value may slightly differ from one supplier to another

2.1.2 Flash Point (FP)

Limits of flammability are not very convenient working tools.

Flash point is the common method of classification of flammable liquids and Legal Authorities use it in classification systems. The flash point increases with the boiling temperature of the product. For hydrocarbon solvents that are characterised by a boiling range instead of a boiling temperature, flash point is also determined by the breadth of the boiling range.

Flash point is defined as "the temperature to which a liquid must be heated before it will produce a flammable mixture of vapour in air that will ignite when an ignition source is applied". Continuous combustion will not occur at flash point temperature. This takes place at a higher temperature known as the fire point.

In practice, the temperature at which a flash point is recorded is very close to the temperature corresponding to the LEL. Thus, in most cases, FP instead of LEL/UEL is used as a main indication of flammability properties of a product. In very general terms the lower the flash point the more volatile and hence, potentially hazardous, the material may be.

For practical purposes flash point can be regarded as the lower temperature limit of flammability.

Flash point determination in the laboratory can be influenced by many factors e.g. testing equipment, size of the sample, ignition source, temperature, ambient pressure, sample homogeneity, draughts and operator bias. During the test, one must take care to ensure that the volatiles are not driven off before the flame is applied. Your solvent supplier will have informed you of the flash point of the materials he supplies to you.

In common with all chemical products, solvents are classified in accordance with legislative requirements for both Supply (Use) and Carriage (Transport) and assigned Risk Phrases. The table below details the criteria and phrases commonly found on material safety data sheets relating to flammability.

European criteria for flammability assignment of risk phrases ^{Ref 14}

	Risk phrases	Classification criteria
R12	Extremely flammable	Boiling point $\leq 35^{\circ}\text{C}$ and flash point* $< 0^{\circ}\text{C}$
R11	Highly flammable	Flash point* $< 21^{\circ}\text{C}$ and not extremely flammable
R10	Flammable liquid	$21^{\circ}\text{C} \leq \text{flash point}^* \leq 55^{\circ}\text{C}$
-	Not classified for carriage	Flash point* $> 61^{\circ}\text{C}$

*Flash points must be indicated in chapter 9 of the supplier's SDS.

2.1.3 Auto-ignition temperature (AIT)

This section is for solvent users working at elevated temperatures

A mixture of solvent vapours in air or oxygen will ignite spontaneously if the temperature is high enough.

AIT is the minimum temperature at which a mixture of combustible vapour and air can ignite **without the presence of an ignition source, under the specified conditions of the test.**

Usually the AIT is well above the boiling point of the material. There is no link with the flash point. The AIT is mainly linked to the chemical structure of the molecule and not with its boiling point.

AIT's are not absolute values but depend greatly on the method by which they are obtained (volume and nature of the matter of the flask). AIT is eminently variable.

AIT are significantly lowered when pressure is increased above atmospheric and the measurement can be affected by the cool flame phenomena already mentioned before, occurring in the 300-400°C region.

The AIT of the solvent you use must be indicated in section 9 of your supplier's SDS.

The most common test method to measure AIT is described in ASTM E659: small quantities of liquid are injected in a glass conical flask (200 cm³) which has been heated to a known temperature. In view of the important potential variations between AIT values and the real auto-ignition conditions of a process, it is important to note that AIT should not be regarded as a clear cut-off point between no-ignition / self-ignition conditions. Instead, AITs are just very rough indications of the maximum temperature to which flammable mixtures can be exposed without self-ignition. It is always advisable to work well below the measured AIT.

2.1.4 Mists of flammable liquids

As opposed to vapours, fine mists of solvents may be flammable well below their flash point.

Mists of solvents can be generated in two ways:

- uncontrolled condensation of saturated vapours resulting in droplets (mists) whose diameter is below 0.02 mm.
- atomised sprays with a range of diameters from 0.02 up to 1 or 2 mm.

Mists are common in degreasing of metal parts by spraying techniques.

Because they behave like vapours, droplets with sizes ranging between 0.02 to 0.2 mm are likely to assist flame propagation (which is necessary for flammability to occur).

The mist will be capable of propagating the flame if the quantity of solvent present is high enough. Explosion could occur in confined conditions.

Mists are also characterised by lower (LEL) and upper explosion limits (UEL) in the same way as vapours; it is nevertheless difficult to obtain reliable measures of LEL and UEL for mists due to the lack of uniformity of the droplets.

Lower explosive limits are strongly affected by droplet size. Generally, the larger the droplet diameter, the higher the LEL.

In situations where mists or sprays cannot be avoided, specific safety measures must be taken. Consult a specialist.

2.1.5 Minimum ignition energy: MIE

Whatever the potential source of ignition may be, it needs to deliver a certain level of energy to trigger the combustion of hydrocarbon vapours. However, very low energy levels are sufficient to ignite solvent vapour/air mixtures (as an indication, energy between 0.1 and 1 millijoule is enough to ignite a flammable vapour). The minimum ignition energy is really quite low, and close to the threshold of human perception of an electrical shock (like the occasional shock when opening a car door). A spark of a calculator, of a mobile phone, of a metal tool falling on the floor or of an electrical switch is enough to initiate a fire if the solvent vapours in air are within the flammable range concentration.

Most sources of ignition encountered in industrial activities will exceed the MIE of solvents and require strict control.

2.2 SOURCES OF IGNITION

Sources of energy can be classed into 4 categories:

2.2.1 Flames and smouldering

Under this heading come all naked flames: such as welding torches, matches, and gas burners, as well as sporadic sources such as the exhaust of an engine.

Smouldering covers all forms of incandescent material such as cigarettes, and less obviously, catalysts.

2.2.2 Hot surfaces

Hot surfaces occur widely in industry and may cause ignition of flammable solvent/air mixtures either directly or indirectly.

Direct ignition will occur if the surface is at a temperature above the auto-ignition temperature of the solvent-air mixture in the particular conditions considered.

Indirect ignition results from the burning or smouldering of material initiated by a hot surface.

Hot surfaces are widespread in industrial areas: as examples, walls of ovens and furnaces, electrical equipment, and heating pipes. Some operations can easily produce hot spots: as examples, grinding, cutting and welding operations.

2.2.3 Friction and impact

Hot surfaces and incandescent sparks mainly arise from friction, and depend largely on the materials: for example, sparks produced during impacts involving metals (magnesium and their alloys, iron) with grit or rock generate high heat.

2.2.4 Electrical discharges

There is specific legislation aimed at ensuring that operators have adequately considered the risks posed by electricity. The regulations require operators to classify their sites in terms of zones (ANNEX 3). Electrical discharges are widespread and often hidden. They usually arise from two basic sources:

- Electrical power
 - Main grid electricity as well as batteries are sources of sparks with sufficient energy to ignite solvent vapours-air blends: normal operations of transformers, motors, circuit breakers, switches, fuses as well as electrical failures such as damaged cables are common electrical ignition sources.

Electromagnetic waves emitted by radio antennae may give rise to sparks in their vicinity or to a heat build-up of materials.

- Electrostatic discharges
 - Static electricity is a phenomenon of great importance when handling solvents, in particular hydrocarbon solvents. This is such an important source of incidents that the final part of this guide is fully dedicated to this aspect.

PART 3 Static electricity

3.1 INTRODUCTION

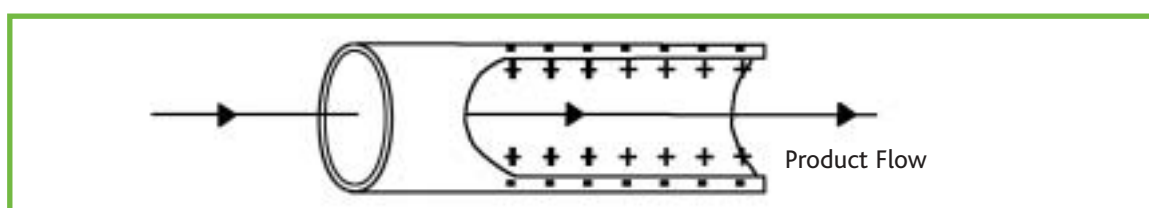
One of the most difficult ignition sources to understand and control is that of static electricity. Similar operations can produce different levels of static on different days, and often the first indication of static is a spark, which may of course be catastrophic in the presence of solvent vapours. This section of the guide gives a detailed account of how best to manage the threat of static electricity, along with some practical applications and mitigation techniques.

3.2 STATIC ELECTRICITY

Static electricity is produced by pumping of materials or by any other means of motion, such as agitation. The movement separates positive and negative charges, which then accumulate in the liquid and the containment system (lines, tanks, drums etc). The charge on the containment system is dissipated quickly by earthing, but the charge in the liquid remains and is slowly dissipated, depending on the conductivity of the liquid.

Static charges can accumulate in liquids with a conductivity of less than 50 picosiemens/metre (pS/m). In such liquids, high potential differences can be created, that can discharge into powerful sparks capable of causing ignition of solvent vapours. Discharges can occur from insulated conductors (plant items, drums), bulk liquids, mists and insulating plastic materials.

The following diagram shows what occurs during pumping a liquid through a line.



The more turbulent the flow the more static electricity is produced. Turbulence is explained in ANNEX 1.

3.2.1 Conductivity of solvents

The static charge built up within a liquid will dissipate by migrating from the liquid to an earthing point. The rate of dissipation depends on how readily the liquid will conduct electricity. Hydrocarbon solvents, with a very low conductivity (typically less than 10 pS/m), do not readily conduct electricity. Oils boiling in the range of 350-500°C are in fact used as insulators in large transformers and have extremely low conductivities. Such products are capable of retaining a significant charge even when in contact with earth. More polar materials such as alcohols, ketones and acetates readily conduct electricity as can be seen by the table below. Care should however be taken with all flammable industrial solvents. The following table of conductivities (Table 2) is from empirical data^{Ref 13} using readily available industrial solvents. The figures are for comparison only as the values will vary depending on trace impurities such as water, sulphur, traces of acids or even trace quantities of metals present. Care must be taken when measuring conductivities to ensure that the result has not been distorted by polarisation, and that a high enough oscillating current has been used during the measurement.

Table 2

Substance	Conductivity pS/m
Acetone	6 x 10 ⁶
Methyl Ethyl Ketone	5 x 10 ⁶
n-Butanol	4 x 10 ⁶
Iso-Propanol	2 x 10 ⁶
Ethyl Acetate	2 x 10 ⁶
n-Butyl Acetate	2 x 10 ⁶
Ethanol	4 x 10 ⁶
Methanol	7 x 10 ⁶
n-Heptane	4
n-Hexane	24
Iso Octane	1
n-Octane	9
Toluene	5
n-Pentane	24
m-Xylene	9

Water entrained in a hydrocarbon solvent increases its electrostatic generation potential when it is handled. It is not unusual to have water in solvents resulting from operations such as water washing or line flushing. Care should thus be taken to avoid unnecessary mixing.

3.2.2 Relaxation time

Electrostatic charges gradually dissipate after a time called the relaxation time (τ), which depends on the permittivity and the conductivity of the material:

$$\tau = \frac{\epsilon \epsilon_0}{\gamma} \times 10^{12}$$

Where

τ = Relaxation time in seconds

ϵ = Relative permittivity of the liquid

ϵ_0 = Permittivity of the free space
(8.85 x 10⁻¹² F/m)

γ = Conductivity of the liquid (in pS/m)

For most low conductivity liquids, as an approximation, $\tau = 18/\gamma$

For example, a liquid with a conductivity of 0.5 pS/m (e.g. classical mineral spirits) will have a relaxation time of about 36 seconds, while for deaerated mineral spirits, the typical relaxation time would be in the range of 260 seconds or 4 to 5 minutes. For aromatic solvents, it would be in the range of a few seconds.

Highly refined materials, especially hydro-treated gas oils with sulphur contents below 50 ppm, appear to have a higher risk of electrostatic ignition.^{Ref 10}

In general, it is recommended to adopt a safety margin of minimum $3 \times \tau$, however, this will vary according to the operations in progress. Individual companies should seek advice from suppliers and safety practitioners.

In practice, the liquid flow systems should be equipped with a relaxation chamber to provide sufficient residence time for the charge to be reduced to a safe level.

3.2.3 Static Dissipation

The dissipation of static electricity is dependent on good connections to earth i.e. resistance less than 10Ω and the conductivity of the material. The value of τ gives the time for 37% of the charge to be dissipated^{Ref 6 Sec 1.8.2.2}. After 3τ , only 5% of the charge should remain.

Operations which generate static charges:

- High velocity and turbulent conditions for example in pipelines, or the discharge of jets from nozzles and tank mixing.
- Filtration, particularly through micropore elements with a large surface area exposed to the flow.
- Liquid droplets or foam falling through a vapour, for example a spray or mist formation in vapour spaces, splash filling of tanks, tankers, drums or intermediate bulk containers, especially if the tank is of plastic.
- Settling water droplets through liquid hydrocarbon i.e. after a line has been pigged off into a tank with water.
- Bubbling of gas or air through liquids.
- Mechanical movements such as belts or pulleys used as air blast coolers.
- The movement of vehicles, fans or even people.
- Movement or transport of powders, although not relevant in the case of solvents. There have been many incidents involving harmless materials such as flour, where static build up has caused an explosion of flour dust.
- High velocity release of steam to atmosphere.

3.3 MITIGATION MEASURES (Storage and Handling)

3.3.1 Tank and Vessel Earthing and Bonding:

- Earthing establishes a continuous electrical path to earth.
- Bonding ensures that all the plant is at the same equal potential.

Major stationary pieces of equipment can be permanently earthed with built-in systems (Figure 1 & 2), but temporary earthing and bonding must be ensured for loading/unloading operations, drum filling.



Figure 1. Typical bottom loading stand with earth connection

Figure 2. Typical mobile earthing for drums



The earthing/bonding of tanks and vessels is essential to reduce the likelihood of static discharge and potential plant damage from^{Ref 5 Sec 2.1}.

- Faults between live conductors and non-current carrying metal work.
- Lightning strikes.
- Induced currents and voltages from radio frequency radiation.
- Accumulation of static charges.

It is important to note that the earthing/bonding approach does not prevent the generation of static electricity but helps to eliminate the charges built during handling and to help avoid discharges as sparks.

3.4 TANK / TANK TRANSFERS ^{Ref 6 Part 2 Sec 13.3.4}

The first step in a transfer operation involving a tank car or truck should be to attach a temporary earth connection to the car or truck. The final step should be the removal of the connection. Splash filling into a tank should be avoided by the use of main inlet line at low level, or a fill pipe to the tank bottom.

When transferring liquids with conductivities below 50 pS/m (i.e. hydrocarbons) the linear velocity should be kept below 1m/s until the inlet pipe is covered to twice its diameter. After this the pumping rate could increase up to 7 m/s but it is advisable to keep as low as reasonably practicable, typically 2-3 m/s. If a second phase is present i.e. water, the pumping rate should be kept to 1 m/s.

3.5 DIPPING AND SAMPLING

Once a tank has been transferred or mixed it may be necessary to dip or sample.

During the period of transfer or agitation, static charge will have built up within the tank, sufficient time must be allowed for this charge to dissipate (relaxation time). Most hydrocarbon tanks contain a small amount of second phase i.e. water and the recommended relaxation period before sampling or dipping is 30 minutes ^{Ref 6 Part 2 Sec 6.3.2}, unless a fixed sampling or sounding tube is fitted.

Dipping or sampling ^{Ref 6 Part2 Sec 6.2} must not be carried out whilst transferring or mixing.

The equipment for dipping should be of metal or natural fibre and be earthed. Sampling cords should also be of natural fibres with resistivities which are unlikely to give rise to the accumulation of static charge.

Dipping and sampling of flammable liquids should not be carried out in extreme adverse weather conditions ^{Ref 6 Part 2 Sec 6.4} i.e. snow or hail storms or during a thunderstorm.

3.6 LOADING AND FILLING OPERATIONS (transportable metal items)

3.6.1 Road / Rail (bulk)

During filling operations, whether tank car or truck or a storage tank, the discharging liquid should not be allowed to fall through the vapour space since this causes the liquid to take on a static charge relative to the tank shell (even though the tank is grounded).

When being filled, unless special earthing connections are made, the resistance to earth of a lorry with pneumatic tyres on dry concrete could well exceed $10^6 \Omega$. Provision must be made to reduce this resistance to 10Ω . Ref 6 Part 2 Sec 7.2.1

Rail tanks are earthed through the rail, during loading there is no requirement to use a special earth. If any doubt exists on the electrical continuity between the running gear and the tank, then a special earth should be used with a maximum resistance of 10Ω to earth. Ref 6 Part 2 Sec 9.4.1

All hoses should be electrically conductive.

Splash filling a tank should be avoided by employing bottom entry or by using a fill pipe terminating close to the bottom of the tank. At the start of filling the pumping rate should be no greater than 1m/s. Ref 6 Part 2 Sec 7.3.1

Once the inlet pipe is covered to twice its diameter, the pumping rate can be increased but should always be kept below 7 m/s ($u \leq 7$). Ref 6 Part 2 Sec 7.3.3

The recommended pumping rate can be calculated in terms of linear velocity u (in m/s) and the diameter of the pipe d (in metres):

$$ud \leq N \quad \text{where } N \text{ is between } 0.38 \text{ and } 0.5 \text{ m}^2/\text{s}.$$

Thus for a 100 mm pipe the maximum linear flow should be 5 m/s during loading. This figure should not be exceeded and in practice the pumping rate would normally be lower than this, typically nearer 1.5 m/s which would be about 42,000 litres/hour.

These filling rates do not apply to switch loadings into bulk road vehicles (see below).

If a fine filter is used the static charge must be allowed to dissipate before filling the lorry (relaxation). A relaxation chamber Ref 6 Sec 2.21 is part of a liquid flow system which provides sufficient residence time for the charge to be reduced to a safe level.

This may involve introducing a large earthed pipe section (relaxation chamber) into a loading system before discharge into the road/rail tank. There have been several publications specifically on the safety of loading of road tankers with fuel and the associated risks of static ignition. Ref 8, 9 & 10

The formula above was developed for use with hydrocarbons and would indicate that there is little requirement to allow a dissipation time for polar solvents. However there is still a finite time required for the charge to dissipate and containers must still be earthed.

ISO containers must be earthed directly to the loading system and will tend to build up a greater charge as they are normally one compartment of about 30-35 m³ capacity, rather than a multi-pot vehicle where the typical compartment is 7.5 m³. The charge build up is reduced where there are baffles as they help to dissipate the static.

The use of compressed air or water for line clearance of products with low flash points should be avoided.

3.6.2 Switch Loading

Switch loading is where the compartments are not cleaned between deliveries and a product is loaded where there is vapour from the previous load. This is a hazardous practice with low conductivity products, especially where the previous load was flammable and the next load is high flash and viscous. There have been several incidents of explosion/fire arising from this practice. In cases where switch loading cannot be avoided, special precautions must be taken.

- Ideally, all compartments that have previously contained flammable liquids should be gas freed before loading the second liquid. Since this is not always practical, the following recommendations should be borne in mind: Organise loading schedules to minimise switch loading.
- Ensure that all dip tubes/filling arms/pipes are adequately earthed.
- Keep maximum loading rates at half the level of the pumping rates calculated according to the equation mentioned on the previous page.

3.6.3 Filling IBC Containers (metal)

These should not be splash filled and must be earthed directly back to the loading system. The frame around the IBC may or may not be bonded to the tank. The tank usually rests in brackets and contains cushioning materials to absorb shock during transit and, unless there is an earthing strap between the frame and the tank, both the tank and frame should be earthed. If there is earth bonding between the tank and frame only one earthing point is needed.

Filling should be to the bottom of the IBC and the linear fill velocity should not exceed 1 m/s.

There is no means of measuring the volume filled into the metal IBC and IBC's must be loaded via a metering system to ensure overspill does not occur.



Figure 3. Typical metal IBC

3.6.4 Filling IBC Containers (plastic)

The cost of metal IBC's is high and there is a trend to the use of plastic IBC's with their much lower cost and availability. Plastic IBC's cannot be earthed unless there is special provision within the container. Low flash solvents (i.e. with flash points below 35°C approximately) should not be filled into plastic IBC's as static charge could build up during filling and take considerable time to dissipate (see SIA guidance on filling IBC's). Filling materials with a flash point below ambient temperature will mean that the vapour concentration above materials will go from zero to between the lower and upper explosion limits, and either exceed the upper explosion limit or remain within the band, thus increasing the risk of a fire/explosion occurring.

Under these circumstances it is inadvisable to use plastic IBC's, as there is no guarantee that the static charge will dissipate safely. Plastic IBC's are, however, approved for the transport of flammable liquid under ADR/RID regulations and can be safely used for some high conductivity solvents such as alcohols and ketones. It is recommended that the solvent supplier should be consulted if there is any doubt.



Figure 4. Typical plastic IBC (Note earth connection shown for information only)

3.6.5 Filling drums / cans

Drums/cans should not be splash filled and must be earthed directly back to the loading system. Filling should be to the bottom of the drum/can and the linear fill velocity should not exceed 1 m/s. There is no means of measuring the volume filled into a drum or can and filling should be via a metering system to ensure overspill does not occur. Drums and cans must be earthed with a special earth clip that penetrates the paint coating and ensures that the earth resistance is not greater than 10 Ω .

3.7 GENERAL

All electrical equipment used in solvent service must be explosion proof and ordinary flashlights and extension cords should not be used.

No insulated conductor from which an incendive discharge could occur (e.g. metal can, steel rimmed spectacles, steel comb or pen) should be inadvertently dropped or introduced into tanks during filling, sampling or discharging operations.

Procedures should be in place to regularly check equipment requirements in relation to earthing resistance and electrical conductivity of hoses.

Blending

Where personnel are involved in emptying bags or drums into non-conductive liquids, they should wear conductive or anti-static footwear and gloves, and clothing should not be removed in areas where a flammable atmosphere may be present. In some cases, these precautions are not sufficient and the floor may need to be treated. The operator's total resistance to earth via footwear and floor should not exceed 10^8 Ohms.

Anti-static additives

Anti-static additives work by migration of the additive to the tank walls carrying the charge with them, thus reducing the relaxation time after pumping. However, the anti-static additives continue to migrate to the tank walls even after the charge has dissipated. A material dosed with anti-static additive slowly returns to its original state of low conductivity and care must be taken to ensure that the additive is still active if pumping at high linear velocities is to take place.

ESIG does not recommend the addition of anti-static additives to solvents for the sole purpose of mitigating static build-up (though they may be added for other application purposes in some cases). Customers in the past have assumed the addition makes them safe to use without any other precautions, resulting in accidents.

Anti-static additives are used in aviation fuels and the conductivities of the fuel are regularly checked to ensure compliance with specifications.

ANNEX 1 Turbulent flows

The Reynolds Number ^{Ref 2 Sec 5-4} is a measure of turbulence within a pipe. The Critical Reynolds Number when flow changes from laminar to turbulent is about 2-3000 ^{Ref 2 Sec 5-4}. Table 3 shows the Reynolds Number for 4" (100 mm) pipe and a 2 centipoise viscosity liquid.

The Reynolds Number is calculated as:

$$\frac{\rho \times d \times v}{\mu}$$

ρ = Density
 d = Pipe diameter
 v = Velocity
 μ = Viscosity

Table 3

Flow m/s	Diameter m	Density kg/m ³	Viscosity centipoise	Viscosity kg/m*s	Reynolds Number	Pumped Volume l/hour
0.5	0.1	800	2	0.002	20000	14137
1.0					40000	28274
1.5					60000	42412
2.0					80000	56549
2.5					100000	70686
3.0					120000	84823
3.5					140000	98960
4.0					160000	113097
4.5					180000	127235
5.0					200000	141372
5.5					220000	155509
6.0					240000	169646
6.5					260000	183783
7.0					280000	197920

ANNEX 2 IP Electrical safety code

The IP Electrical Safety Code Ref 6 Table 4 Part 1BS5958 and Ref5 Sec 2.5.1 recommends the following:

Table 4

Type of installation	Electrical Zones	Recommended Maximum resistance to earth Ω	Comments
Tanks	0,1,2	10	Normally 2 earthing connections are required but on larger tanks more are needed. See Notes 1 & 2 below.
Large fixed metal plant	0,1,2	10	Earthing is normally inherent in the structure. Occasionally items may be mounted on non-conducting supports and special earthing connections may be required.
Metal pipelines	0,1,2	10	Earthing is 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.
Transportable metal containers (drums, ISO containers, IBC's road and rail tanks etc.)	0,1,2	10	Special earthing connection will normally be required.

More information on other structures can be obtained from the IP Electrical Safety Code and BS 5958.

NOTE 1

The IP Electrical Safety Code recommends that tanks over 30 metres diameter should have 3 earth connections. BS 6651^{Ref 7} Sec 22.2.5.1 on lightning protection, recommends that metal structures should be protected by earthing and that the earthing points should not be more than 10 metres apart, equally spaced. A 30-metre diameter tank would therefore require 9 earthing points. The lightning protection for a tank is far greater than that required for safe static dissipation.

NOTE 2 REF 6 PART 1 SEC 13.2.2

Calculations have shown that a safe resistance to earth for static dissipation of $10^6 \Omega$ and even $10^8 \Omega$ is safe in many situations. The code points out that achieving an earth resistance of less than 10 Ω presents no practical difficulties and therefore recommends a 10 Ω maximum resistance to earth.

ANNEX 3 Explosive atmosphere regulations (ATEX)

NOTE Existing explosive atmosphere regulations (ATEX 1 and 2) are aimed at addressing the problems by insuring hazardous areas are zoned and that suitable equipment is used:

ZONE 0 An explosive gas/air mixture is continuously present for long periods: ex. inside processing vessels and tanks.

ZONE 1 An explosive gas/air mixture is likely to occur in normal operation:

- Open vessels: vertically from ground level to 1m above the vessel and horizontally 2m from vessel.
- Pumping inside a building: within any enclosure around the pump.
- Metered discharge point: within 2m horizontally of the discharge point and from floor level to 1m above the source.

ZONE 2 An explosive gas/air mixture is not likely to occur in normal operation or only for a short time. Ignition sources should not be present in a zoned area; any work within these areas, maintenance or repair must be subject to risk assessment or a "permit to work" system.

- | | |
|-----------------------------|--|
| • Closed process vessels | vertically from ground level to 2m above the vessel and horizontally 2m from the vessel. |
| • Open vessel | horizontally 2m beyond the zone 1 boundary and vertically to a height of 3m if the zone 1 area is <3m in height. |
| • Pumping inside a building | within a horizontal radius of 4m and vertically from the ground level 2m above the unit. |
| • Metered discharge point | horizontally 2m beyond the zone 1 boundary and vertically to a height of 3m if the zone 1 area is <3m in height. |

GLOSSARY

Included below are only the technical items that have not been defined within the text.

Bonding	The use of an additional independent connection between conductors to provide electrical continuity when this cannot otherwise be ensured.
Combustible	Capable of burning in air when ignited.
Flammable	Capable of being ignited. See table on page 7 for European criteria for flammability assignment of risk phrases.
Incendive	Having sufficient energy to ignite a flammable mixture.
IBC	Intermediate Bulk Container.
Inert	Incapable of supporting combustion; to render incapable of supporting combustion.
Static Accumulator	A liquid which, by virtue of its very low conductivity, is capable of retaining a significant electrostatic charge when in contact with earth.

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