

STATIC ELECTRICITY**Table of Contents**

	Page
1.0 SCOPE	4
1.1 Changes	4
2.0 LOSS PREVENTION RECOMMENDATIONS	4
2.1 Introduction	4
2.2 Occupancy	4
2.2.1 Transmission Machinery	4
2.2.2 Coating and Spreading	4
2.2.3 Printing and Lithographing	4
2.2.4 Mixing and Blending	4
2.2.5 Lacquer and "Dopes", Reclamation of Waste	4
2.2.6 Film Casting and Extrusion	4
2.2.7 Solvent Extraction Plants	4
2.2.8 Cleaning Operations	5
2.2.9 Spray Application of Flammable and Combustible Materials	5
2.2.10 Textiles	5
2.2.11 Plastic Containers and Plastic-Lined Containers	5
2.2.12 Flammable Anesthetic Agents	5
2.2.13 Dusts	5
2.2.14 Gases	5
2.3 Electrical	5
2.3.1 Bonding and Grounding	5
2.3.2 Humidity Control	5
2.3.3 Ventilation	6
2.3.4 Static Eliminators	6
2.3.5 Clothing	6
2.3.6 Container Filling and Discharge	6
2.3.7 Static Elimination and Neutralization	7
2.3.8 Platforms	7
2.3.9 Tables and Bench Tops	7
2.3.10 Piping	7
2.3.11 Conductive Bodies	7
2.3.12 Dusts	7
2.3.13 Anesthetizing	8
2.3.14 Static Testing	8
3.0 SUPPORT FOR RECOMMENDATIONS	8
3.1 Loss History	8
4.0 REFERENCES	8
4.1 FM	8
4.2 NFPA Standards	8
APPENDIX A GLOSSARY OF TERMS	8
APPENDIX B DOCUMENT REVISION HISTORY	8
APPENDIX C INFORMATION ON STATIC	9
C.1 General	9
C.2 How Static Electricity Is Generated	9
C.3 Triboelectric Series	10
C.3.1 Energy in a Static Discharge	10
C.3.2 Static Accumulation By Personnel	11

C.4 Static Control	11
C.4.1 Bonding and Grounding	11
C.4.2 Ionization	12
C.4.3 Humidification	15
C.5 Control Of Ignitable Mixtures	15
C.5.1 Inerting, Ventilation, Relocation	15
C.6 Ignitable Liquids	15
C.6.1 Free Charges on Surface of Liquid	16
C.6.2 Storage Tanks	17
C.6.3 Closed Piping Systems	17
C.6.4 Rubber-Tired Vehicles	17
C.6.5 Tank Cars, Tankers, and Barges	18
C.6.6 Container Filling	18
C.6.7 Plastic and Plastic-Lined Containers	19
C.7 Gases	20
C.7.1 General	20
C.7.2 Air Under Pressure	20
C.7.3 Carbon Dioxide	20
C.7.4 Hydrogen-Air, Acetylene-Air Mixtures	20
C.7.5 LP Gases	20
C.8 Dusts And Fibers	20
C.8.1 General	20
C.8.2 Ignition of Dust by Static Discharge	21
C.9 Transmission Machinery	23
C.9.1 General	23
C.9.2 Flat Belts	23
C.9.3 Conveyor Belts	23
C.9.4 Pulleys and Shafts	24
C.10 Coating, Spreading, And Impregnating	24
C.11 Printing And Lithography	24
C.11.1 General	24
C.11.2 Paper	25
C.11.3 Inks	25
C.11.4 Presses	25
C.11.5 Mixing and Blending Operations	26
C.12 Plastics	26
C.12.1 Lacquers and Dopes	26
C.12.2 Film Casting and Extrusion	26
C.12.3 Reclamation of Waste	27
C.13 Solvent Extraction Plants	27
C.14 CLEANING OPERATIONS	27
C.14.1 Dry Cleaning	27
C.14.2 Steam Cleaning	27
C.15 Spray Application Of Flammable And Combustible Materials	27
C.16 Textiles	27
C.16.1 Cotton Gins	28
C.17 Flammable Anesthetic Agents	28
C.18 Static Detection And Measurement	28
C.18.1 Field Mills	28
C.18.2 Electrostatic Voltmeter	28
C.18.3 Electrometers	29
C.18.4 Handheld Devices	29
C.18.5 Electroscopes	29
C.18.6 Neon Lamps	29
Fig. 1. Methods of grounding shafts or metal rollers. Carbon brush and holder, brass or carbon brush, spring bronze brush.	12

List of Figures

Fig. 1. Methods of grounding shafts or metal rollers. Carbon brush and holder, brass or carbon brush,
spring bronze brush. 12

Fig. 2. Static collectors. Tinsel spirally wound on wooden bar, crimped bronze wire set in metal back, and copper or bronze bristles set in twisted wire.	13
Fig. 3. Static Removal from nonconducting materials. (National Fire Protection Association)	14
Fig. 4. Electrically energized neutralizer.	14
Fig. 5. Filling tank truck through open dome. (National Fire Protection Association)	18
Fig. 6. Filling or emptying tank truck through a closed connection. (National Fire Protection Association) .	18
Fig. 7. Bonding during container filling. (National Fire Protection Association)	19
Fig. 8. Details and location of static comb.	23
Fig. 9. Grounding of cloth coating machine (metal frame) showing location of static eliminators. (National Fire Protection Association)	24

List of Tables

Table 1. Approximate Resistivities of Some Pure Ignitable Liquids	16
Table 2. Minimum Electrical Energy (Millijoule) For Ignition of Some Dust Clouds and Layers	22

1.0 SCOPE

This data sheet describes how static electricity is generated in commercial and industrial operations where it is a potential fire and explosion hazard. The methods used for preventing its accumulation so as not to cause ignition are discussed. It also covers the control of static electricity in areas where flammable anesthetic agents are used, and where a potential explosion hazard may exist.

1.1 Changes

April 2012. Terminology related to ignitable liquids has been revised to provide increased clarity and consistency with regard to FM Global's loss prevention recommendations for ignitable liquid hazards.

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 Introduction

To protect against the static hazard involved with the following processes or occupancy, the numbered recommendations as listed below under 2.3 *Electrical* should be applied as indicated.

2.2 Occupancy

2.2.1 Transmission Machinery

2.2.1.1 Preferably employ antistatic belts made of conductive materials.

2.2.1.2 Grounded metal combs or tinsel bars should be applied on ordinary belts where the belts leave the pulleys as illustrated in Figure 1.

2.2.1.3 If materials on a conveyor carry a charge that may be troublesome where they spill off the end of a conveyor belt into a hopper or chute, bond the belt support and terminal pulleys to the hopper or chute. Also apply Recommendations 1a to f, whichever are suitable.

2.2.2 Coating and Spreading

2.2.2.1 Apply Recommendations in Sections 2.3.1 through 2.3.5 and in 2.3.7; and recommendations 2.3.6.1 and 2.3.8.1.

2.2.3 Printing and Lithographing

2.2.3.1 Apply Recommendations in Sections 2.3.1 through 2.3.5 and recommendations 2.3.6.1 and 2.3.7.2.

2.2.4 Mixing and Blending

2.2.4.1 Apply Recommendations in Sections 2.3.1 through 2.3.5 and recommendation 2.3.6.1. Where flammable mixtures are likely to be present above the liquid surface in a container, inert gas blanketing may be employed. See Data Sheet 7-32, *Ignitable Liquid Operations*.

2.2.5 Lacquer and "Dopes", Reclamation of Waste

2.2.5.1 Apply Recommendations in Sections 2.3.1 through 2.3.3. Use conductive solvents if available, or add conductive agents.

2.2.6 Film Casting and Extrusion

2.2.6.1 Apply Recommendations in Sections 2.3.1 through 2.3.4.

2.2.7 Solvent Extraction Plants

2.2.7.1 Apply Recommendations in Section 2.3.1, and bond together all tanks, vessels, motors, pipes, conduits, and building frames within the process.

2.2.8 Cleaning Operations

2.2.8.1 For plants handling ignitable liquids with flash points at or below 100°F (38°C), apply Recommendations in Sections 2.3.1, 2.3.2, 2.3.3, 2.3.5 and 2.3.7.2 and 2.3.9.1. Where steam cleaning is a hazard, bond steam pipes or nozzles to object being steamed.

2.2.9 Spray Application of Flammable and Combustible Materials

2.2.9.1 Apply Recommendations in Section 2.3.1 for all spray booths, exhaust ducts, solvent tanks, and piping conveying ignitable liquids. For airless spray systems, bond the airless equipment to the object being sprayed if the latter is conductive. The handle of the spray gun on electrostatic hand spraying equipment should be grounded to prevent the accumulation of a static charge on the operator. (See Data Sheet 7-27, *Spray Application of Flammable and Combustible Materials*.)

2.2.10 Textiles

2.2.10.1 Apply Recommendation 2.3.2.1.

2.2.11 Plastic Containers and Plastic-Lined Containers

2.2.11.1 If a plastic container is used in a flammable atmosphere, apply Recommendations 2.3.2.1 and 2.3.5.1 through 2.3.5.4, and ground nearby conducting objects.

2.2.12 Flammable Anesthetic Agents

2.2.12.1 See NFPA Standard No. 56A. Apply Recommendations in Sections 2.3.1, 2.3.5, 2.3.8 and 2.3.14. Provide a patient grounding point and a room grounding point as required by the National Electrical Code, Article 517, *Health Care Facilities*, 1981 edition.

2.2.13 Dusts

2.2.13.1 Apply Recommendations 2.3.1.1, 2.3.1.2, 2.3.1.3, 2.3.4.1, 2.3.12.1, and 2.3.12.2. See Data Sheet 7-75, *Grain Storage and Milling*.

2.2.14 Gases

2.2.14.1 Apply Recommendations in Section 2.3.10.

2.3 Electrical

2.3.1 Bonding and Grounding

2.3.1.1 Bond and ground all conductive objects. This is frequently the least expensive method of preventing the accumulation of a static charge.

2.3.1.2 Make sure bond wires are mechanically strong. They need not have large current carrying ability, as the currents involved are minute. Uninsulated bonding and grounding conductors are preferred because their condition is easily determined by a visual inspection.

2.3.1.3 The resistance of the ground connection should not exceed 10^6 ohms. Ground electrodes used for lighting or power circuits or for lightning protection are more than adequate for static grounding purposes. Other grounding methods such as connecting to a sprinkler system, electric conduit system, and the steel frame of a building also are acceptable.

2.3.1.4 Shafts, metal rollers, or similar moving parts on a machine should be grounded as illustrated in Figure 1.

2.3.1.5 All isolated metal parts of the equipment should be bonded and grounded.

2.3.1.6 Shafts that turn at high speeds should be bonded to the journal housing.

2.3.2 Humidity Control

2.3.2.1 Maintain a relative humidity of 60 to 70% or more, wherever possible. Local humidification by means of steam jets installed at the points of static generation is an acceptable method in some applications.

2.3.3 Ventilation

2.3.3.1 Provide ample forced ventilation in the process area and around the equipment where flammable vapors are produced. The ventilating equipment should be interlocked with the process controls so that the process cannot be operated unless the ventilating system is functioning.

2.3.3.2 Where a normally flammable mixture is contained within a small enclosure such as a processing tank, an inert gas may be used effectively to bring the mixture well below its flammable range. (See Data Sheet 7-59, *Inerting and Purging Vessels and Equipment*.)

2.3.3.3 Where an uncontrollable static hazard exists, it is sometimes practical to direct the air flow in such a manner that flammable vapors or dusts cannot approach the operation.

2.3.3.4 Wherever possible, move static generating equipment to a safe location rather than rely on methods of static mitigation.

2.3.3.5 Solvent containers such as hoppers should be enclosed and filled through a closed piping system.

2.3.4 Static Eliminators

2.3.4.1 Provide static eliminators or neutralizers. They should be firmly fixed, well grounded, properly adjusted, and kept clean of foreign accumulations.

2.3.5 Clothing

2.3.5.1 Employees working on hazardous processes or equipment that generates static should wear conductive footwear and stand on conductive floors or platforms. The use of rubbers, rubber boots, rubber soled shoes, or boots with nails or metal heel or toe guards should be prohibited.

2.3.5.2 Soles of shoes and conductive floors and working platforms should be clean and free of any insulating substance.

2.3.5.3 Avoid the use of garments made of silk, wool, and synthetic materials unless the garment is in close contact with the body.

2.3.5.4 People with unusually dry skin should not work with hazardous processes because they accumulate static more readily than others.

2.3.6 Container Filling and Discharge

2.3.6.1 When filling metal containers (pails, drums, tanks, or tank trucks) with ignitable liquids having flash points below 100°F (38°C), or above 100°F (38°C) when heated above its flash point, conductive fill pipes or nozzles should be used, they should make good contact with the container opening or otherwise be bonded to the container. See Figures 6 and 7. Bonds should be attached before the tank is opened and not removed until it is closed.

2.3.6.2 Extend fill pipes for large storage tanks or trucks to the bottom, and arrange to discharge the liquid horizontally to eliminate splash filling and reduce turbulence. If bottom loading is used, splash deflectors should be installed to prevent upward spraying of the liquid.

2.3.6.2.1 The linear velocity of the liquid entering the tank should be kept low, about 3 ft/sec (0.9 m/s), until the inlet pipe is submerged.

2.3.6.2.2 Overshot splash filling should be prohibited.

2.3.6.2.3 Water should be kept out of the incoming stream. If there possibly is a layer of water in the bottom of the tank, avoid agitating so as not to break the surface.

2.3.6.2.4 Avoid pumping of entrained air or gas into a tank that has a vapor space that can generate charges at the free liquid surface.

2.3.6.2.5 Tanks previously used for storing ignitable liquids should be ventilated to at least 50% of the lower flammable limit before pumping in a high flash point static-generating liquid.

2.3.6.2.6 Gauging or sampling of large tanks through roof openings should be avoided for a definite period of time after filling has been completed.

2.3.6.2.7 Care should be taken to prevent any ungrounded floatable object from getting into the tank.

2.3.6.2.8 Metal storage tanks should be grounded if the resistance to earth exceeds 10^6 ohms.

2.3.7 Static Elimination and Neutralization

2.3.7.1 All metal parts of machinery or process equipment involving ignitable liquids or combustible dusts should be in good electrical contact with the grounded machine frame or well bonded to it. This includes the feeder device, spreader knives, doctor blades, metal rolls and containers for the ignitable liquids, conveyor systems, ductwork, mills, and associated equipment. Spray booths, exhaust ducts, and piping should be similarly bonded and grounded.

2.3.7.2 Install Approved static eliminators or neutralizers close to the points where the static is generated. These include areas where the material being processed is unwound, or after it passes under a doctor blade or spreader knife, or passes over a flowing roll, squeeze roll, calendar roll, impression roller, and similar parts of the machine, in addition to any belts and pulleys associated with the machinery.

2.3.7.3 Apply Recommendation 2.3.2.1.

2.3.7.4 Do not use electrically energized static eliminators in hazardous areas unless specifically Approved for the hazard.

2.3.7.5 Open gas flames should not be used for neutralizing a charge on paper if ignitable liquids are used in the process. Where they are used, the gas supply should be interlocked with the process so that the flame is extinguished if the process is stopped.

2.3.7.6 Static collectors or neutralizers should be kept about $\frac{1}{4}$ (6 to 13 mm) to $\frac{1}{2}$ in. away from moving surfaces.

2.3.8 Platforms

2.3.8.1 Working platforms provided around machines processing combustible materials should be constructed of conductive materials or covered with a conductive flooring and grounded. Also apply Recommendations in Section 2.3.5.

2.3.9 Tables and Bench Tops

2.3.9.1 Cover tables or bench tops on which ignitable liquids are used with sheet metal and ground them. Also apply Recommendations in Sections 2.3.5 and 2.3.8.

2.3.10 Piping

2.3.10.1 On closed piping systems, bonds should be provided around those joints in which the contacting surfaces are made of nonmetallic insulating material.

2.3.10.2 In areas where flammable vapor-air mixtures may exist, electrically isolated sections of metallic piping should be bonded to the rest of the system, or grounded, to prevent external sparks, which might cause ignition.

2.3.11 Conductive Bodies

2.3.11.1 Conductive bodies in a hazardous location that may become charged due to exposure to a stream of gas contaminated with solid or liquid particles should be grounded or bonded to the discharge pipe.

2.3.12 Dusts

2.3.12.1 Where combustible dusts or powders are handled or processed, metal and other conductive material should be used in the design of components to facilitate bonding and grounding. Processing equipment should be dust-tight.

2.3.12.2 Where bonding and grounding of all conductive parts may not prevent a static charge on dispersed dust or powder, static neutralizers also may be needed.

2.3.13 Anesthetizing

2.3.13.1 Anesthetizing areas and corridors and rooms that communicate directly with them should have conducting floors and metal furniture, and personnel in these areas should wear conducting footwear. Accessories such as operating tables, stretcher pads, sheeting, pillows, and cushions should be of conductive materials. Woolen and synthetic blankets should not be used. Outer garments worn in these areas should be made of antistatic materials. Silk, wool, or synthetic textiles, except rayon, should not be permitted except for underclothing where the entire garment is in close contact with the skin.

Flexible parts of the anesthesia machine such as tubing, inhalers, rebreathing bags, headstraps, face masks, etc. that are interconnected should be of conductive material so that there is a low resistance electrical path of 1 ohm between them.

The electrical installation in these areas should comply with the requirements specified in Article 517 of the National Electrical Code, NFPA Standard No. 70, 1981 edition.

2.3.14 Static Testing

2.3.14.1 When testing for static in areas containing flammable atmospheres, care should be taken that the instruments or testing techniques that are employed will not cause ignition.

3.0 SUPPORT FOR RECOMMENDATIONS

3.1 Loss History

A study of fires and explosions caused by static electricity, for the ten-year period 1969 through 1978 in FM Global insured properties, showed that 233 losses occurred.

4.0 REFERENCES

4.1 FM

Data Sheet 7-32, *Ignitable Liquid Operations*.

Data Sheet 7-27, *Spray Application of Flammable and Combustible Materials*.

Data Sheet 7-75, *Grain Storage and Milling*.

Data Sheet 7-59, *Inerting and Purgung Vessels and Equipment*.

Data Sheet 7-88, *Ignitable Liquid Storage Tanks*.

Data Sheet 7-29, *Ignitable Liquid Storage in Portable Containers*.

Data Sheet 7-55, *Liquefied Petroleum Gas (LPG) in Stationary Installations*.

Data Sheet 7-76, *Prevention and Mitigation of Combustible Dust Explosions and Fires*.

Data Sheet 7-96, *Printing Plants*.

4.2 NFPA Standards

NFPA Standard 99 *Standard for Healthcare Facilities*

National Electrical Code, Article 517, *Health Care Facilities*

NFPA Standard 70 *National Electrical Code*

NFPA Standard 77 *Recommended Practice on Static Electricity*

APPENDIX A GLOSSARY OF TERMS

This document does not have any defined terms.

APPENDIX B DOCUMENT REVISION HISTORY

April 2012. Terminology related to ignitable liquids has been revised to provide increased clarity and consistency with regard to FM Global's loss prevention recommendations for ignitable liquid hazards.

September 2000. This revision of the document has been reorganized to provide a consistent format.

This document does not have any revision history.

APPENDIX C INFORMATION ON STATIC

C.1 General

The nature and origin of static charges and general methods of static mitigation are discussed in detail in NFPA Standard No. 77. They also are discussed in somewhat less detail in this data sheet.

The generation of static electricity cannot be prevented, but dangerous accumulations can be avoided by conducting the electric charges away as fast as they are produced.

If static electricity is not neutralized or eliminated as rapidly as it is produced, the charge builds up and will eventually develop energy enough to jump as a spark to some nearby grounded or less highly charged object. The spark can ignite nearby combustible materials or vapors.

Methods of preventing the charge buildup include bonding, grounding, ionization, and humidification. They will be described in more detail later in the text. These methods may be used singly or in combination, and will help to prevent a spark discharge by allowing the separated positive and negative charges to recombine harmlessly.

Some of the more common processes in which static charges are produced are as follows:

1. A rapidly moving belt running over a pulley.
2. Paper or cloth passing through a machine and over rollers or under a doctor blade.
3. Nonconducting liquids flowing through a pipe or hose, or falling through the air in drops or as a spray.
4. Agitation of nonconducting liquids in tank or when air or other gases bubble through them. Petroleum solvents, benzine, ether, and carbon bisulphide readily produce and accumulate static charges.
5. Gas issuing from a nozzle at high velocity, especially when carrying liquid or solid particles.
6. Movement of stock in grain handling and storage plants.
7. Processing plants for feed, seed, spices, sugar, starch, cocoa, resin, and similar materials.
8. Manufacture of metal powders, aluminum, etc.
9. Powders and granular materials falling through pipes or dropping off the ends of conveyors.
10. Paper passing through a printing press.
11. Dry cleaning processes employing nonaqueous liquid solvents.
12. Mixing, grinding, screening, or blending operations with solid non-conductive materials.
13. Moving vehicles.
14. Pulverized materials passing through chutes or pneumatic conveyors.
15. Aircraft in flight or on the ground.

Most methods for preventing static accumulations provide a means whereby the charges that have become separated will recombine harmlessly before sparking potentials are attained.

C.2 How Static Electricity Is Generated

Static electricity is caused by the movement of electrons when two dissimilar substances in contact are separated. While they are in intimate contact, a redistribution of the electrons is likely to occur across the interface, and as equilibrium is achieved, an attractive force is established. When the two substances are separated, work must be done in opposition to these forces. The expended energy reappears as an increase in voltage between the two surfaces.

When an electric charge is present on the surface of a nonconductive body from which it cannot escape, that charge is called static electricity. Likewise, if the body is conducting, but the charge cannot escape because it is in contact only with other nonconductors, that charge is also called static electricity. The charge may be either positive or negative, depending on an excess or a deficiency in electrons. For example, a surface that has an excess or a deficiency of one electron in every 100,000 atoms is very strongly charged.

A body that is charged is one in which an electrical imbalance exists. The charge is on the surface. If it is a conductor, it is free to move over the surface under the influence of charges on nearby bodies. If the charges are the same, they will be repelled; if they are unlike, they are attracted. If the charge is on a nonconductor, it is stationary and would remain indefinitely if the body is a perfect insulator. However, since a perfect insulator is non-existent from the practical standpoint, a charge on the surface will remain but a fraction of an hour at most. If there is a conducting path between the separated charges, they will reunite immediately. If there is no such path available, a potential of several thousand volts can develop.

When static electricity is generated by the separation of two dissimilar substances, at least one of them is usually an insulator. The creation of a static potential immediately causes a flow of current, which permits the separated charges to reunite following any available conducting paths. If the two charged bodies are highly insulated from each other because the conducting paths are of high resistance, a potential of several thousand volts may develop before the discharge rate equals the rate of generation. If under these conditions the two bodies are brought close together, the potential may be sufficiently high to produce a visible spark. In the presence of combustibles, such sparks are a potential ignition hazard.

A charge on the surface of an insulated conductive body is free to move. The entire charge can be drained off by a single spark. But a charge on the surface of an insulator is relatively stationary, and a spark from its surface will release the charge from only a small part of the surface. It will usually have insufficient energy to cause ignition.

A charged object has a strong influence on nearby objects. If the latter is a conductor, it will experience a separation of charges by induction. Induced charges may be more dangerous than the initially separated charges because a repelled charge is free to give or receive electrons. If another conductor is moved nearby, the transfer may occur by means of a spark. Likewise, sparks may occur when the inducing charge is moved away from the insulated conductor.

C.3 Triboelectric Series

Materials differ in their ability to attract or lose electrons when they are in contact with one another. They are so different that the various materials can be listed according to their ability to acquire electrons, as shown in the following list known as the *Triboelectric Series*. Each of the materials listed will become positively charged when in contact with any material lower on the list.

Triboelectric Series

+

Asbestos
Glass
Mica
Wool
Cat fur
Lead
Silk
Aluminum
Paper
Cotton
Woods, Iron
Sealing Wax
Ebonite
Nickel, Copper, Silver, Brass
Sulphur
Platinum, Silver
India Rubber

—

C.3.1 Energy in a Static Discharge

Static electricity is a source of ignition when a spark discharge has sufficient energy to ignite nearby combustible materials. The minimum ignition energy varies for different combustible mixtures. Energy in a spark discharge is equal to $\frac{1}{2} CV^2 \times 10^{-9}$, where the energy is in millijoules (mj), C is the capacitance in micro-microfarads (picofarads), and V is the potential in volts. The energy in a static spark is also influenced by

the electrodes (objects) between which the spark takes place. All sparks do not have the same ignition capability even though they contain the same amount of energy. Fast sparks do not transfer the heat to the entire mixture, and slow sparks result in a cold discharge. Metal-to-metal discharges usually provide a hot spark capable of ignition.

Voltages on objects may vary from a few volts to several hundred thousand volts. A potential of 10,000 volts could be expected under average conditions. This voltage would be hazardous in the case of an isolated object the size of a baseball with spark electrodes of almost any shape.

Although the capacitance of an object depends on its physical dimensions and its nearness to other objects, most pieces of machinery have a capacitance from one hundred to a few thousand picofarads. Capacitance of the human body is estimated to be about 200 picofarads. Assuming an insulated object is charged to 10,000 volts, the energy in the spark discharge would be about 50 mj from a machine or about 10 mj from a person. These energies are sufficient to ignite many combustibles.

In general, hydrocarbon gases and vapors require about 0.25 mj of energy for ignition with air. Acetylene is a notable exception; in air it needs about 0.02 mj. The minimum energies for bituminous coal and cornstarch dust clouds are about 60 and 30 mj, respectively.

Accordingly, a spark from a charged conducting object the size of a large man may be hazardous if the potential is a little more than 1500 volts and the spark occurs between small electrodes.

In the case of a 10,000 volt spark in a combustible mixture of hydrocarbon and air, the capacitance of a charged conductor would have to be less than 5 picofarads to be safe. On the other hand, an isolated object the size of a baseball charged to the same voltage could be hazardous with spark electrodes of almost any shape. Similarly a 20,000 volt spark would need a capacitance of 1.25 picofarads or a charged electrode about the size of a large marble or a 20 penny nail. Such a spark in air would be at least $\frac{1}{4}$ inch (6 mm) in length.

When some portion of a large nonconductive surface, such as an oil surface or power belting, acquires a charge density of 3×10^{-9} coulombs per cm^2 , the potential gradient will exceed the dielectric strength of air, which is about 30,000 volts per centimeter. Small brush discharges or corona may appear, making the region conductive. With an adequate charging process, a spark from this conductive surface area may have enough energy to ignite a flammable vapor-air mixture.

C.3.2 Static Accumulation By Personnel

The human body may frequently accumulate a dangerous static charge by contact of shoes with floor coverings or by working close to machinery that generates static electricity. However, the shoes and clothing of workers may be moist enough to drain away static charges as fast as they are generated. In dry weather or in rooms where humidity is low, static charges may accumulate on the bodies of workers to a potential of several thousand volts, which can cause ignition in hazardous locations.

C.4 Static Control

C.4.1 Bonding and Grounding

In hazardous locations, all isolated metal parts of machines that may produce static electricity should be bonded and the machine grounded. *Bonding* is the act of electrically connecting two or more conducting objects with a conductor. *Grounding* is the process of electrically connecting one or more conducting objects to ground. In some countries grounding is referred to as "earthing."

The main purpose of bonding and grounding is to minimize potential differences between the metallic objects and between the objects and the ground. Bonding keeps two objects at the same potential; thus, no spark discharge can occur. Grounding the conducting object drains away the static charges as rapidly as they are produced. Thus, the threat of sparks is eliminated because there is no longer a difference in potential between the charged object and other nearby objects.

The currents found in the bonding and grounding connections are measured in microamperes. Because of the small currents involved, ground connections of low resistances are not essential. It is only necessary to have sufficient conductivity to carry off the charges before they build up to sparking potentials. A ground resistance as high as 1,000,000 ohms is usually adequate for static grounding. Methods of grounding shafts and metal rollers are illustrated in Figure 1.

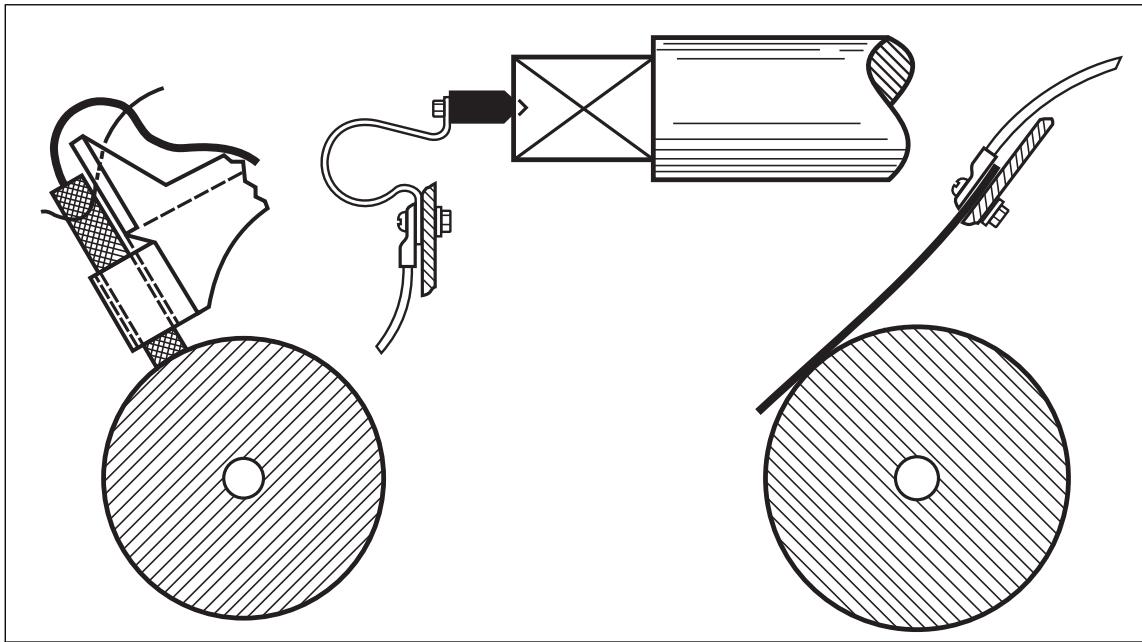


Fig. 1. Methods of grounding shafts or metal rollers.
Carbon brush and holder, brass or carbon brush, spring bronze brush.

Some objects such as a large steel tank resting directly on the ground need no special ground connection as they are inherently grounded.

Conductive Floors. In some hazardous locations, an electrically conductive floor or floor covering may be needed to ground persons and conductive objects.

Hospital operating rooms are examples of locations where conductive floors are used to prevent hazardous accumulations of electrostatic charges. The floor serves as a means of connecting the persons and objects together electrically to minimize the chance of a spark discharge.

It is recommended that electrical apparatus energized from a grounded system not be used or operated by persons standing on the floor.

The resistance of a conductive floor, as determined by special measurements, should be between 25,000 and 1,000,000 ohms. (See NFPA Standard No. 99.) The higher limit is adequate for static charge dissipation; the lower limit gives protection to personnel against electrical shock.

Personnel and objects in the area should be in good electrical contact with the floor. Conductive footwear and metal frames or movable equipment that make contact with the floor directly or through conductive rubber tips or casters can be used.

The test procedure for determining if the resistivity of a conducting floor is within acceptable limits is described in NFPA Standard No. 99, Annex 2.

C.4.2 Ionization

When static charges are produced on nonconducting materials, such as paper, cloth, rubber, or leather, it is not possible to drain off the static electricity or neutralize it by ordinary grounding or bonding methods. If it is impractical to increase the conductivity of the material so that the static charges will be conducted to a grounded metal roll or other machine parts, other static corrective measures such as ionization are necessary.

If a nonconducting charged object is brought into contact with ionized air, the static charge is dissipated. The charge is either conducted to ground through the ionized air, or the static charge on the object attracts a sufficient number of oppositely charged ions from the air to neutralize it.

Air can be ionized by heat, high voltage, ultraviolet light, or radioactivity. Ionization overstresses the air molecules, and electrons are separated from the molecules. The electrons are negatively charged, and the molecules that have lost them become positive in polarity. If an object has a negative charge, the positive ions in the air are attracted to it. If there are enough positive ions in the surrounding air, the negative ions on the object will be neutralized and a static charge will not accumulate.

Heat. Ionization by a row of small gas flames is sometimes used on printing presses to eliminate static electricity on the paper.

Static Collectors or Neutralizers (Non-electrically Energized Type). Ionization of the air near a charged object can be accomplished by non-electrically energized static collectors or neutralizers. When an object charged with static electricity is brought near a sharply pointed, grounded metal object, an electrostatic field is set up between the two objects. The field produces a voltage on the points and when the static charge is above a certain minimum value, spontaneous ionization of the air occurs.

One of the more common non-electrically energized static neutralizers employs a metal bar with numerous grounded brass, bronze, or copper wires having sharp points. Other static collectors are made of metallic tinsel surrounding a metal wire or wound on a wood spar and grounded (Fig.2).

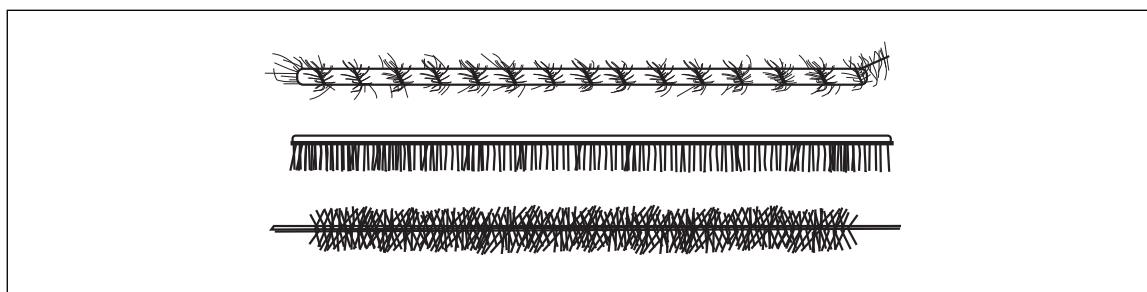


Fig. 2. Static collectors. Tinsel spirally wound on wooden bar, crimped bronze wire set in metal back, and copper or bronze bristles set in twisted wire.

The various unenergized static collectors have about the same degree of effectiveness since they operate on the same principle. They are low in cost and economical to install. See Fig. 3 for typical applications.

Electrically Energized Neutralizers. Static charges on certain materials may be neutralized by passing the charged material through an alternating field of positive and negative ions. Electrically energized neutralizers produce such a field between electrified points and a grounded member, which may be a part of the neutralizer. By locating the neutralizer where the static charges are accumulating, the air is ionized by the high-voltage field and the charges are neutralized.

This principle of increased ionization of the air by sharply pointed conductors connected to a high-voltage electric supply is employed in several makes of static neutralizers. One type is illustrated in Fig. 4.

Static neutralizers of this type employ rows of pointed electrical conductors connected to the high-voltage secondary of a small step-up transformer, usually supplied from a 110- or 220-volt circuit. Although the potential is several thousand volts (about 5,000 to 12,000), conductors are well insulated, the points well guarded, and the current capacity limited.

Static neutralizing and air-cleaning assemblies also are available. This equipment reduces the hazards or the nuisance of static charges by directing an ionized air stream from an ionizing air gun or nozzle onto the material being air-cleaned. It is intended for cleaning surfaces to which dirt and dust are electrostatically attracted, or for separating sheets of plastic, paper, and similar materials. The equipment also may be used for dusting objects before painting them. With the electrostatic charges neutralized by the ionized air, dust and dirt are more easily removed by the air stream and are not re-attracted to the material being cleaned.

Radioactive Static Neutralizers. Air also can be ionized by radioactive materials. Either radium or polonium is used to emit alpha particles, which ionize the air between the neutralizer and the charged object.

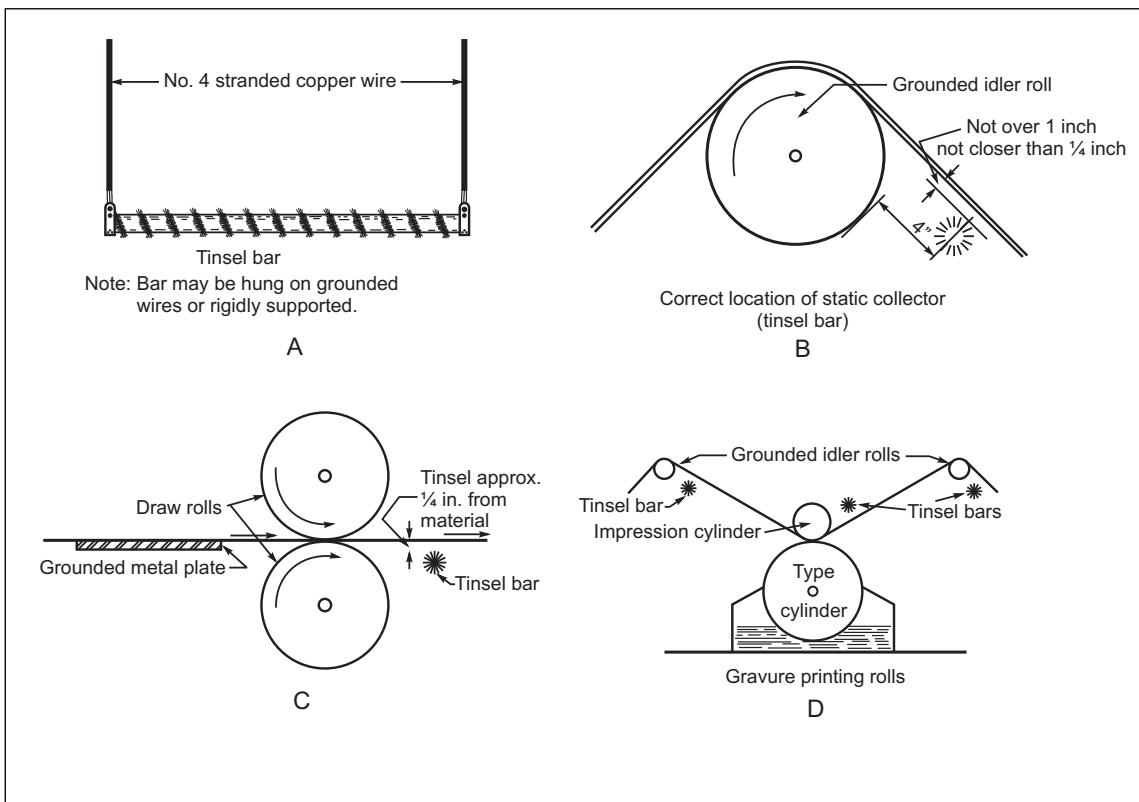


Fig. 3. Static Removal from nonconducting materials. (National Fire Protection Association)

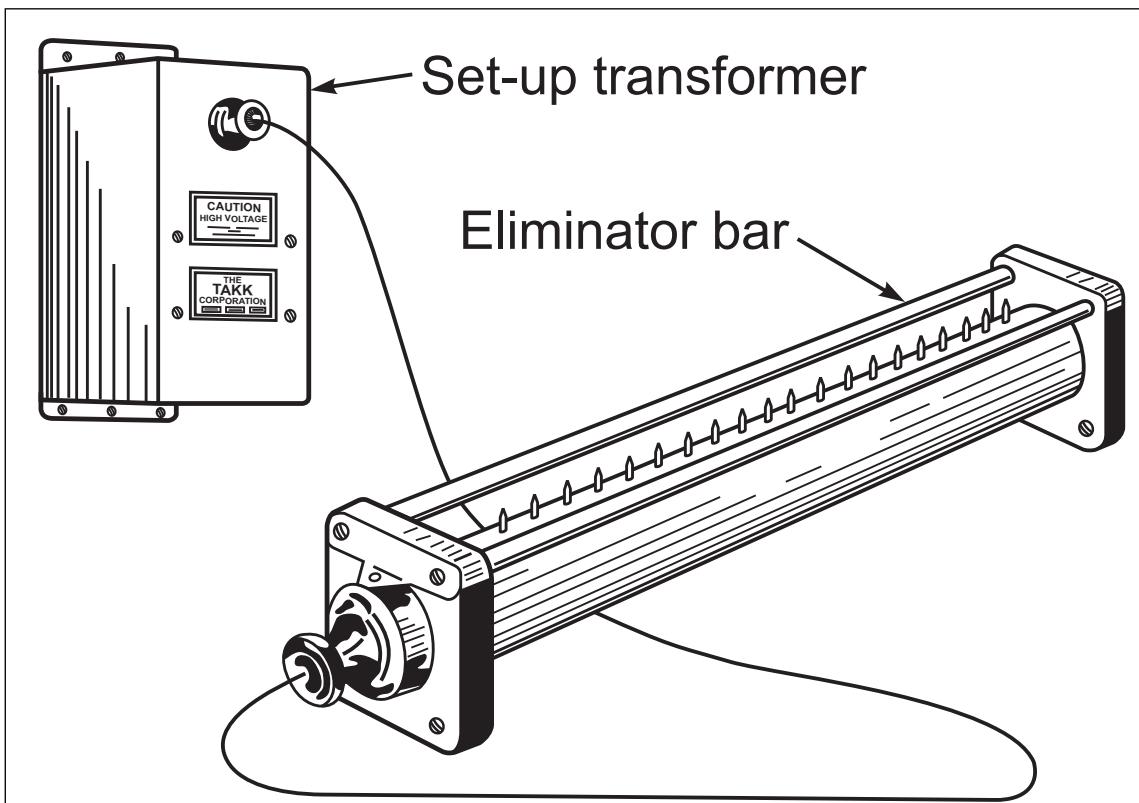


Fig. 4. Electrically energized neutralizer.

As no external power is required, these neutralizers do not constitute an ignition hazard and they can be used in hazardous locations. The fabrication and distribution of radioactive static eliminators is licensed by the U. S. Nuclear Regulatory Commission (or Agreement State Licensing Agency) which is responsible for the health and safety of the general public.

C.4.3 Humidification

Artificial humidification is an effective means of preventing accumulation of static charges on some nonconducting bodies and materials. The humidity provides a minute film of moisture over material, thereby increasing conductivity and providing a suitable path to ground for any charge that develops. In some cases high humidity may adversely affect the quality or the appearance of a manufactured product and other methods of static neutralization may be necessary.

A relative humidity of 60 to 70% will generally produce enough moisture on material to prevent accumulation of static. Even though static electricity is generated, the charge usually leaks away and no accumulation results.

Low relative humidity promotes static generation. Most static electricity fires occur in the winter when the indoor relative humidity is 30% or less and when there is little or no surface moisture on the materials in process.

When high humidity is maintained over a large area, it does not always follow that the same degree of humidity prevails at all parts of the process. If parts of machines are operated at high temperatures, the relative humidity near the heated parts may be low and local humidification or some other method of removing static charges may be needed. Unless automatically controlled, the humidity should be checked periodically. Local humidification, such as by steam jet, may satisfactorily prevent the accumulation of static charges.

C.5 Control Of Ignitable Mixtures

C.5.1 Inerting, Ventilation, Relocation

There are many operations and processes involving ignitable liquids and combustible dusts in which the generation of static can cause fires or explosions, but they do not lend themselves to the usual methods of static mitigation. In these cases this hazard can usually be controlled by one or more of the methods described in Section 2.3, *Electrical*. Also see Data Sheet 7-59, *Inerting and Purging Vessels and Equipment*.

C.6 Ignitable Liquids

Static electricity can be generated when ignitable liquids are being handled or stored. It can occur when the liquid is discharged from a pipe or a hose, transferred from one container to another, or agitated, mixed, or pumped. A spark from a static charge accumulated during such operations can ignite a flammable vapor-air mixture that may be present.

Ignitable liquids can hold a static charge. The ability of the liquid to retain a charge depends to a large extent on the resistivity of the liquid. If the liquid has a resistivity of less than 10^{10} ohm-cm, any charges that are generated will generally be neutralized and will not accumulate to a dangerous potential. A liquid having a resistivity greater than 10^{10} ohm-cm may accumulate a charge. Thus, a nonconducting ignitable liquid can accumulate a dangerous charge on its surface.

Under some conditions water is a good generator of static electricity, but because of its low resistivity and wetting properties, charges leak away as rapidly as produced and electrification is not observed.

Experience indicates that crude oils do not produce static ignitions.

In general, when a liquid is handled at a temperature such that the vapor-air mixture at the liquid surface is approximately midway between the upper and lower flammable limits, conditions are optimum for ignition. These conditions occur when the liquids are handled at temperatures that are slightly above their flash points; as the handling temperature increases or decreases, the probability of ignition decreases.

Ignitable liquids with flash points below 100°F (38°C) present the most serious static electricity hazard. This also applies to ignitable liquids with flash point at or above 100°F (38°C) when heated above their flash point. Static control measures are not needed for unheated ignitable liquids with flash points at or above 100°F (38°C).

The amount of charge on the surface is governed by the rate of charge entering and being separated in the tank, compared with the rate at which the charge reunites with its opposite sign. The reuniting, in turn, is controlled by the dielectric constant and the resistivity of the liquid. With a high charge concentration on the surface of a liquid, an electrostatic field is produced in the vapor space. This field can have sufficient potential gradient (30,000 volts/cm) to ionize the vapor and provide a low-resistance conducting path over which a spark may jump. The time for these charges to reunite or relax may last from a fraction of a second to a few minutes.

Antistatic additives are sometimes added to a petroleum liquid to increase its conductivity. This method of minimizing the generation of static electricity is not yet used to any extent. Even if antistatic additives are used, it is advisable to retain other measures for lessening the static hazard.

Table 1 gives the approximate resistivities of some pure ignitable liquids. These values alone are not reliable for predicting the static hazard because test methods differ and fuels are rated in different orders.

Table 1. Approximate Resistivities of Some Pure Ignitable Liquids

Liquid	Resistivity, ohm-cm
Acetaldehyde	5.9×10^5
Acetic acid	8.9×10^8
Acetic anhydride	2.1×10^6
Acetone	1.7×10^7
Ethyl acetate	1.0×10^9
Ethyl alcohol	7.4×10^8
Heptane	1.0×10^{13}
Hexane	1.0×10^{15}
Methyl acetate	2.9×10^5
Methyl alcohol	2.3×10^6
Methyl ethyl ketone	1.0×10^7
n-Butyl alcohol	1.1×10^8
n-Octadecyl alcohol	2.8×10^{10}
n-Propyl alcohol	5.0×10^7
Sulfuric acid	1.0×10^2
Toluene	1.0×10^{14}
Water	2.5×10^7

Source: British Industrial Solvents Division Distillers Company Ltd. *Interim Report on the Mitigation of Static in Storage Tanks, and Table of Resistivities of Some Pure Liquids*, by N. MacDonald, Shawinigan Resins Corp., September 22, 1955.

Note: Resistivities of commercial products may differ from the above.

Note: Reported values of some petroleum products range from 10^8 to 10^{16} .

C.6.1 Free Charges on Surface of Liquid

If an electrically charged liquid is poured, pumped, or otherwise transferred into a tank or container, the unit charges of similar sign within the liquid will be repelled from each other toward the outer surfaces of the liquid. The surfaces in contact with the container walls and the top surface adjacent to the air space, if any, will receive the charge. It is this latter charge, often called the *surface charge*, that is of most concern.

If the potential difference between any part of the liquid surface and the metal tank shell should become high enough to cause ionization of the air, electrical breakdown may occur and a spark may jump to the shell. This spark across the liquid surface is in an area where flammable vapor-air mixtures are normally present. Bonding or grounding of the tank or container cannot remove this internal surface charge.

Further generation or separation may occur within the container in several ways to produce a surface charge:

1. Flow with splashing or spraying of the incoming stream, often called splash filling,
2. Disturbance of a water bottom by the incoming stream,
3. Bubbling of air or gas through a liquid, or
4. Jet or propeller blending within the tank.

Surface charges can be rendered harmless by inerting the vapor space, by displacing part of the oxygen with a suitable inert gas, or by increasing the concentration of flammable gas in the vapor space to above the upper flammable limit with a gas, such as natural gas.

C.6.2 Storage Tanks

Storage tanks are of two general types: those having a vapor space and those having substantially no vapor space. A cone-roof tank is an example of the former, and a floating-roof tank is an example of the latter. (See Data Sheet 7-88, *Ignitable Liquid Storage Tanks*.)

When cone-roof tanks, or other spaces that may contain flammable mixtures of vapor and air, are filled with static-generating liquids, one or more of the protective measures specified under Recommendation 2.3.6.2 may be used, depending upon the characteristics of the liquid handled. However, no special precautions are necessary on floating roof tanks once the roof becomes buoyant.

C.6.3 Closed Piping Systems

Flow through metallic piping generates static, but experience has indicated closed piping systems present no static hazard. This also applies to glass and plastic piping systems. (See Data Sheet 7-32, *Ignitable Liquid Operations*.)

Bonding is not needed around flexible metallic piping or metallic swing joints even though lubricated.

C.6.4 Rubber-Tired Vehicles

Vehicles equipped with pneumatic rubber tires sometimes accumulate a charge of static electricity from rolling contact of tires on the pavement, or filling fuel and cargo tanks.

Static from vehicle motion is generated at the point of separation of the tire from the pavement. It becomes significant only at high speed operation when tires and pavement are dry and hence, good insulators. Drag chains (drag straps) as a means of bleeding the static charge back to the road as fast as generated are ineffective and unnecessary.

During filling the fuel tank or cargo tank of automotive equipment with a product having static-generating ability, a charge is carried into the tank and will produce a charge on the vehicle. The total charge depends on the generating characteristics and the total quantity of the product delivered. The generation rate is thus a function of delivery rate.

If the vehicle were perfectly insulated from ground, the voltage produced for any given delivery would be determined by the capacitance of the vehicle. Since the tires are not perfect insulators, some leakage occurs, which limits the peak voltage the vehicle may acquire.

When loading tank trucks through open domes at rates of 100 gpm (3801 lpm) and upward, a significant potential may develop between the vehicle and the grounded piping system, and a spark may jump between the edge of the tank opening and the fill pipe.

Proper bonding between the fill pipe and the tank as illustrated in Figure 5 will prevent sparking at this point. Such bonding is not required: (1) when loading vehicles with products not having static-generating abilities, such as asphalt and crude oil; (2) where tank vehicles are used exclusively for transporting ignitable liquids with flash points at or above 100°F (38°C), loaded at racks where no ignitable liquids are handled with flash points below 100°F (38°C); (3) where vehicles are loaded or unloaded through closed connections; or (4) where ignitable liquids are unloaded into underground tanks as shown in Figure 6. A closed connection is one where contact is made before flow starts and is broken after flow is completed.

Switch loading is a term used to describe a product being loaded into a tank or compartment that previously held a product of different vapor pressure. Switch loading present a static hazard when low vapor pressure products are put into a cargo tank containing a flammable vapor from previous usage, e.g., furnace oil loaded into a tank that last carried gasoline.

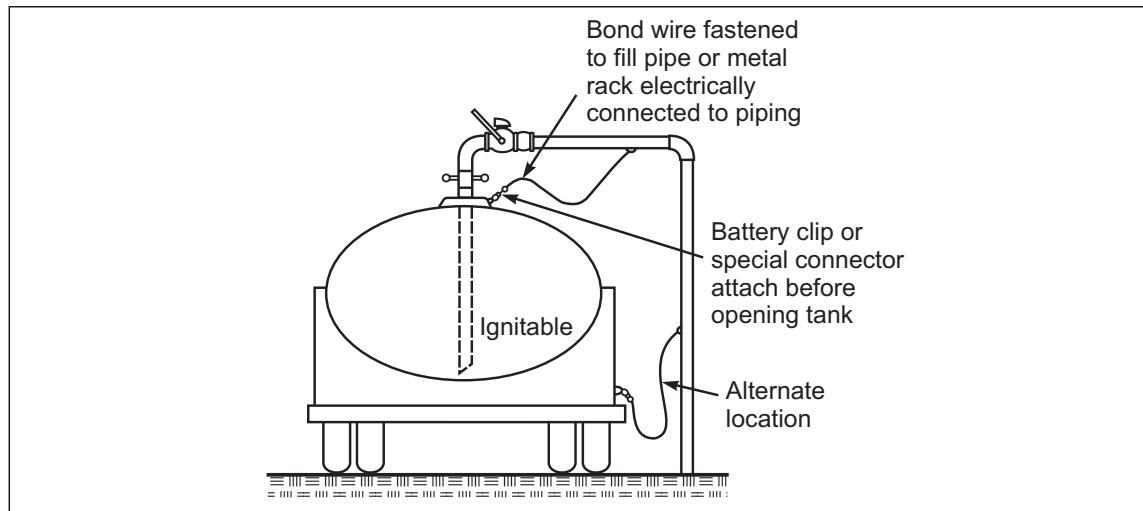


Fig. 5. Filling tank truck through open dome. (National Fire Protection Association)

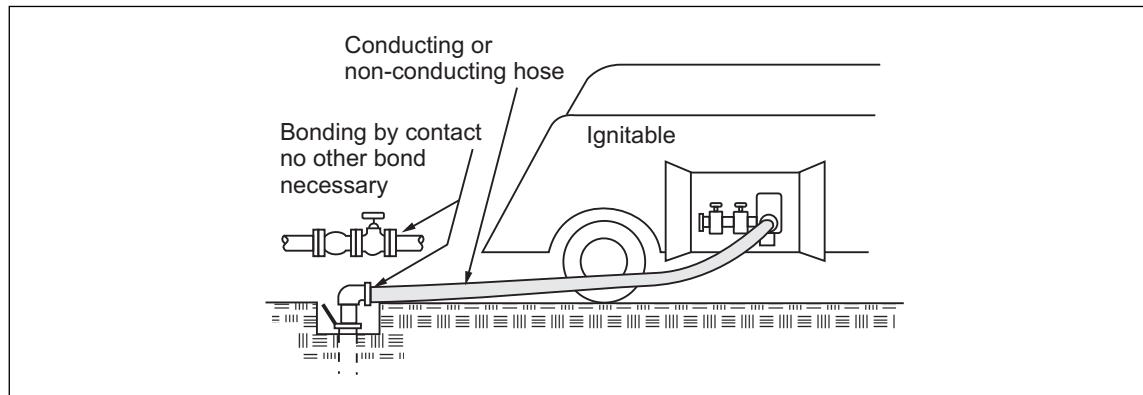


Fig. 6. Filling or emptying tank truck through a closed connection. (National Fire Protection Association)

C.6.5 Tank Cars, Tankers, and Barges

When loading or unloading tank cars through closed connections, no protective measures need be taken. The resistance of tank car to ground through the rails and the resistance of piping, flexible metallic joints, or metallic swivel joints are low enough to protect against static electricity. When loading through open domes, however, the precautions for tank trucks should be observed.

The loading and unloading of steel tank ships and barges does not require special measures to protect against external static sparks. The hull of the vessel is inherently grounded by virtue of its contact with the water.

Loading or discharging liquids from vessels through closed systems in adequate contact with the earth will prevent external static sparks. Even in the unlikely event that an external static spark did occur, it would also be unlikely that this would occur in the presence of a flammable vapor-air-mixture.

Bonding cables, which are often used between ship and shore are sometimes erroneously referred to as "static cables." The purpose of such cables is to prevent arcs caused by stray electrical currents.

C.6.6 Container Filling

Filling portable containers is analogous to filling tank vehicles. See Data Sheet 7-29, *Ignitable Liquid Storage in Portable Containers*.

Experience indicates that when filling containers up to and including 55 gallon (208.2 liter) drums, the downspout need not extend to the bottom. Containers of glass are usually filled without special precaution.

Bonding is not required where a container is filled through a closed system. When the transfer of liquids is not through a closed system, methods of bonding the containers are shown in Fig. 7.

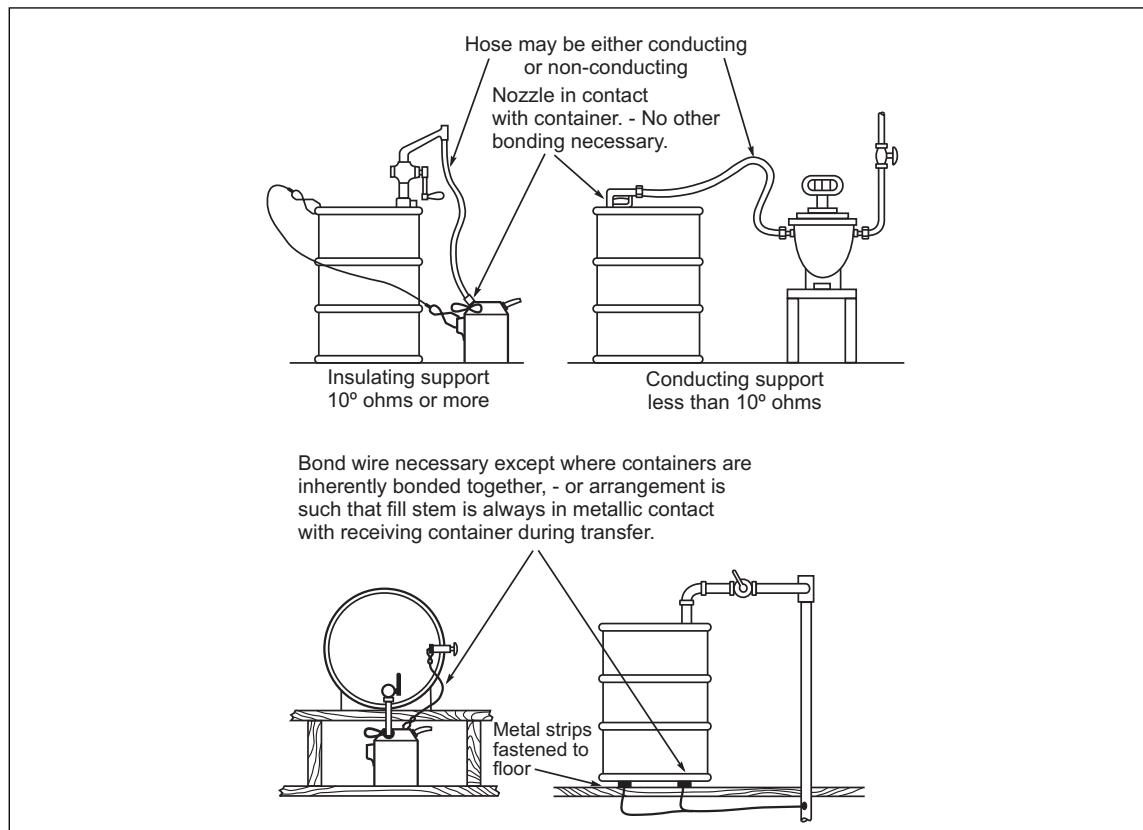


Fig. 7. Bonding during container filling. (National Fire Protection Association)

C.6.7 Plastic and Plastic-Lined Containers

Plastics, because of their high volume resistivity, retain static charges that are generated by various means. Tests have shown that when flammable materials of high resistivity, 10^{10} ohm-cm and above, are handled in polyethylene containers of 6 and 20 gallon (23 and 75 liter) capacity, the containers can become charged. This happens when they are filled with a charged liquid or solid material or by rubbing the surface with some other material. Larger plastic containers such as 55 gallon (208.2 liter) drums are also potentially hazardous when being filled. Charges are generated on the contents by triboelectric mechanisms, which are trapped internally and cannot dissipate to ground.

Filters and insulated pipes in the outlets from the filling system are conducive to static generation. Bottom filling with a grounded lance will help to relax the charge. A grounded band surrounding the drum is helpful in reducing the electric field at the surface of the liquid, which is the most vulnerable location.

External metal near the containers or the drum can become charged by induction and should be grounded if in a hazardous atmosphere.

Polyethylene liners for fiber drums filled with finely divided combustible organic salts or similar free flowing granular or powdered materials may accumulate static charges sufficient to cause ignition of the powder. Static accumulation can be controlled by the use of static-resisting polyethylene liners.

C.7 Gases

C.7.1 General

Gases not contaminated with solid particles have been found to generate little, if any, electrification in their flow. When the flowing gas is contaminated with metallic oxides or scale particles, etc., or with liquid particles or spray, electrification may result. A stream of such particle-containing gas directed against a conductive body will charge the latter.

When any gas is in a closed system of piping and equipment, the system need not be electrically conductive or electrically bonded.

C.7.2 Air Under Pressure

Compressed air containing particles of condensed water vapor often manifests strong electrification when escaping.

C.7.3 Carbon Dioxide

Carbon dioxide, discharged as a liquid from orifices under high pressure (where it immediately changes to a gas and "snow"), can result in static accumulations on the discharge device and the receiving container. This condition is like the effect from contaminated compressed air or from steam flow where the contact effects at the orifice play a part in the static accumulation.

C.7.4 Hydrogen-Air, Acetylene-Air Mixtures

Hydrogen-air and acetylene-air mixtures may be ignited by a spark energy of as little as 0.017 millijoule. Static charges are not generated by the flow of pure hydrogen. Gaseous hydrogen flowing through pipelines, discharging through valves at filling racks into pressure containers, or flowing out of containers through nozzles may contain particles of oxide carried off from the inside of pipes or containers. Contaminated hydrogen gas may generate static.

C.7.5 LP Gases

For liquefied petroleum gases (LP gases), bonding is not required where vehicles are loaded or unloaded through closed connections. (See Data Sheet 7-55, *Liquefied Petroleum Gas (LPG) in Stationary Installations*.) There is no release of vapor at a point where a spark should occur, whether the hose or pipe used is conducting or nonconducting.

C.8 Dusts And Fibers

C.8.1 General

Dust explosions are possible wherever materials that give off combustible dusts are handled, stored or manufactured. (See Data Sheet 7-76, *Prevention and Mitigation of Combustible Dust Explosions and Fires*.)

Electrostatic charge generation in moving dust cannot normally be prevented. High humidity or grounding of the surface from which dust is dispersed will not eliminate the charge generation.

C.8.2 Ignition of Dust by Static Discharge

The voltage developed by dispersion of dust from a surface is proportional to the quantity of dust dispersed. The maximum voltage developed depends on the leakage resistance in the system and corona or spark discharge.

Dust clouds and layers of many combustible materials (with or without a volatile constituent) have been ignited experimentally by energies typical of those found in a static discharge.

At minimum dust concentrations, a relatively high energy is required for ignition. At higher dust concentrations (5 to 10 times the minimum), the energy required for ignition is at a minimum.

In all instances in which static electricity was authentically established as the cause of ignition, the spark occurred between an insulated conductor and ground.

The minimum electrical energies required to ignite some dust clouds and layers are listed in Table 2. (Also, see Data Sheet 7-76, Table 2.)

Table 2. Minimum Electrical Energy (Millijoule) For Ignition of Some Dust Clouds and Layers

Material	Dust Cloud	Dust Layer
Alfalfa	320	—
Allyl alcohol resin	20	80
Aluminum	10	1.6
Aluminum stearate	10	40
Aryl sulfonyl hydrazine	20	160
Aspirin	25	160
Boron	60	—
Cellucotton	60	—
Cellulose acetate	10	—
Cinnamon	40	—
Coal, bituminous	60	560
Cocoa	100	—
Cornstarch	30	—
Cork	35	—
Dimethyl terephthalate	20	—
Dinitro toluidine	15	24
Ferro-manganese	80	8
Gilsonite	25	4
Grain	30	—
Hexamethylenetetramine	10	—
Iron	20	7
Magnesium	20	0.24
Manganese	80	3.2
Methyl methacrylate	15	—
Nut shell	50	—
Paraformaldehyde	20	—
Pentaerythritol	10	—
Phenolic resin	10	40
Phthalic anhydride	15	—
Pitch	20	6
Polyethylene	30	—
Polystyrene	15	—
Rice	40	—
Seed (clover)	40	—
Silicon	80	2.4
Soap	60	3,840
Soybean	50	40
Stearic acid	25	—
Sugar	30	—
Sulfur	15	1.6
Thorium	5	0.004
Titanium	10	0.008
Uranium	45	0.004
Urea resin	80	—
Vanadium	60	8
Vinyl resin	10	—
Wheat flour	50	—
Wood flour	20	—
Zinc	100	400
Zirconium	5	0.0004

Note: Data from U.S. Bureau of Mines.

C.9 Transmission Machinery

C.9.1 General

Some types of power transmission machinery frequently exhibit static generation, which may or may not warrant corrective measures depending on circumstances.

C.9.2 Flat Belts

Rubber or leather flat belts running at moderate or high speeds may generate sufficient static electricity to produce sparks several inches long. Such belts are usually dry and good insulators because friction causes them to operate at temperatures higher than the surrounding atmosphere. Generation occurs where the belt leaves the pulley as a result of the separation. It may occur with either conducting or nonconducting pulleys.

Static generation may be minimized by employing antistatic belts, which are made of conductive materials. It also may be minimized by applying a special type of conductive dressing to the belt. The antistatic belts are preferred because their conductivity is more permanent, while the dressings must be renewed frequently to be reliable.

A grounded metal "comb" with sharp points, placed with the points close to the inside of the belt and a few inches away from the point where it leaves the pulley, will be effective in draining off most of the static (Fig. 8). Such devices may sustain mechanical damage, and are seldom used on power equipment, although this same principle is electrically equivalent to the *tinsel bars* that are often used on paper handling machinery (Fig. 2).

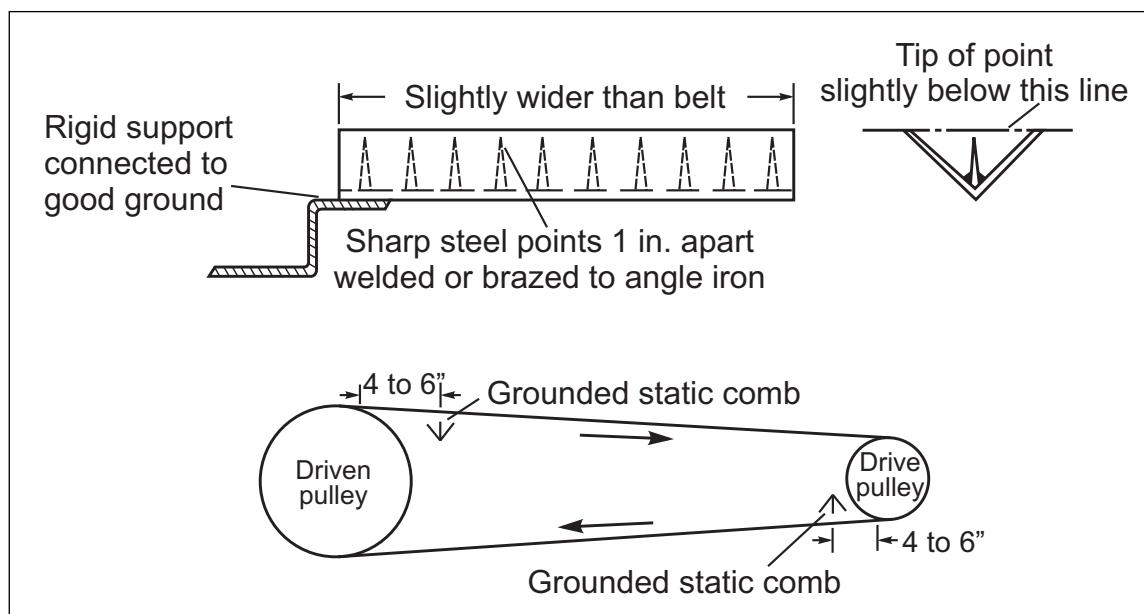


Fig. 8. Details and location of static comb.

V-belts are not as susceptible to hazardous generation of electric charge as flat belts. Under certain conditions of temperature and humidity, however, a V-belt drive may generate a significant quantity of static electricity. Where flammable vapors may be present, it is good practice to use V-belts of the static conducting type.

Conducting type V-belts should be kept free of accumulations of nonconducting material.

C.9.3 Conveyor Belts

Belts used for the transportation of solid material that move at low velocity are not normally static generators. However, if the materials transported are heated or are very dry, or if the belt operates in a heated atmosphere or moves with high velocity, generation might be significant. Materials spilled from the end of a conveyor belt into a hopper or chute may carry a static charge.

C.9.4 Pulleys and Shafts

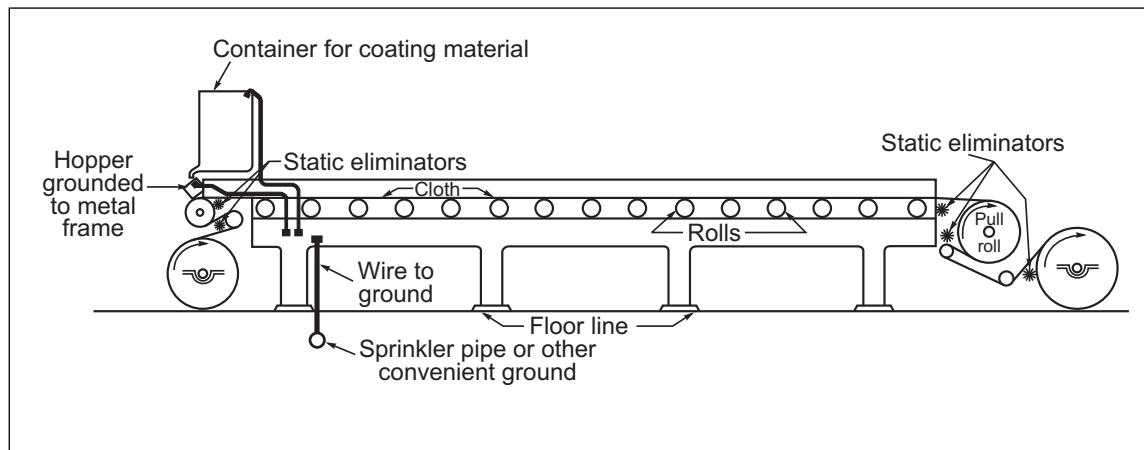
Metal pulleys will pick up a charge equal and opposite to that carried by a belt that runs over them. They will communicate this charge to the supporting shaft, and thence through bearings to the equipment frame and the earth. Generally, machinery frames are sufficiently conductive so that there are no isolated metal parts capable of holding a static charge.

While either ball or journal bearings are sufficiently conductive to carry off static charges from shafts and other rotating equipment, it has sometimes been found that the flow of static electricity across the oil film has resulted in roughening or pitting of bearing surfaces sufficient to adversely affect bearing life.

Shafts that are turning at very high speeds also may be troublesome if the rate of charge generation is high. The leakage resistance across the bearings in such cases may be sufficient to prevent the charge from draining off.

C.10 Coating, Spreading, And Impregnating

Coating, spreading, and impregnating operations are quite similar in that they each involve the application of solutions such as paints, lacquers, rubber compounds, "dopes," and varnish to fabrics, paper, or other materials. Various methods of applying the coating or impregnating material are employed. These include a doctor blade or knife, flowing roll, squeeze rolls, or calendar rolls. Fig. 9 shows a typical cloth coating machine.



*Fig. 9. Grounding of cloth coating machine (metal frame) showing location of static eliminators.
(National Fire Protection Association)*

In each of these operations, the material to be processed usually is unwound from a roll at the feed end of the machine. It passes over a series of rollers under a spreader or doctor knife where the coating material is applied, or through an impregnating tank between squeeze rolls. It then goes under a doctor knife, over a steam table or through a drying oven, and is finally wound up on a reel or laminated on skids. Static charges are often produced in each of these operations.

Electrification depends to a considerable degree on the materials of which the rollers are made.

Where ignitable liquids are employed, adequate forced ventilation for the area and the equipment is of primary importance. If humidification is not injurious to the process, a relative humidity of 60% or more will be helpful in reducing static accumulations. In those areas where high relative humidity can be maintained and adequate forced ventilation is provided, static eliminators may not be needed.

C.11 Printing And Lithography

C.11.1 General

In the printing and lithography industries, static electricity is a frequent source of trouble from the production standpoint. Where ignitable inks and solvents are used in the process, static may create a fire or explosion hazard. (See Data Sheet 7-96, *Printing Plants*.)

Sheets charged with static electricity have an attraction for other objects. This often causes difficulty in controlling the sheets or webs and sometimes tearing of the webs. It also may cause an increase in offset, due to more intimate contact of the surfaces of the sheet in the delivery pile or from the attraction of the ink to the underside of the overlying sheets. The printed image also may be damaged by the attraction of dust particles and loose paper fibers to the paper.

C.11.2 Paper

The character of the paper surface has a great deal to do with the amount of static generated. The rougher surfaced papers generate more static than the smooth-calendered type.

However, the process of calendering paper is, in itself, a source of static generation which, when added to the static generated by the paper passing through the air, will often result in the highly polished calendered paper having a higher charge than the rough surfaced paper. Paper will acquire static charges in the following processes: folding machines, die cutting, eyeletting, deckling, pebbling and roughing, laminating, perforating, stapling, and tipping.

The hygroscopic quality of the paper is also determined to some extent by the character of the surface of the paper. The more water content in the paper, the less static generated. The difficulties in processing cellulose acetate sheets that are moistureproof is an excellent example.

For paper at a relative humidity of 60% or more, there is little need for other means of static control. Other production problems are sometimes introduced by increasing the moisture content. Paper will change in dimension and flexibility with changes in moisture, and registration defects may result.

C.11.3 Inks

Ordinary inks used in the letterpress and lithograph presses have flash points in the 300° to 400°F (154-204°C) range. They present little fire or explosion hazard. High speed printing on rotogravure presses and flexograph presses, however, requires the use of fast drying inks containing low flash point solvents (20-120°F) (-6-49°C) such as naptha, xylol, toluol, or ethyl alcohol. These inks present a potential fire and explosion hazard because of the possibility of ignition of flammable vapor-air mixtures by sparks or other ignition sources.

C.11.4 Presses

The types of presses used in printing plants include letterpress, lithograph, rotogravure, and flexograph. The different types of presses and their hazards are described in detail in Data Sheet 7-96.

Static is generated by the paper running through the press when it is pulled from a roll or stack, when it touches the roll or feeder device that carries it to the printing surface during the actual impression, or in any of the handling equipment provided.

Flexograph presses are widely used for printing on plastics, vinyls, and other synthetic materials. These materials cause more static problems than printing on paper.

The most common method of removing static electricity from presses is by grounding, although grounding the framework in itself is frequently not sufficient protection against static. Static collectors or neutralizers are commonly used in close proximity to the paper. Because static can be generated in many parts of the process, neutralizers may be necessary at a number of locations. Draining the charge from one side of a web of paper does not always drain the charge from the opposite side.

When tinsel bars are used, it is necessary to replace tinsel when it is damaged or when it becomes coated with wax, oil or lint. Static collectors are frequently attached to the fly to assist in removing static from the delivered sheets.

Humidification is one of the most successful methods of controlling static electricity. The amount of moisture required and the method of introducing it in the air differs somewhat with the paper being run and local pressroom conditions. Usually a range from 45 to 60% relative humidity is most practical. Humidification can be accomplished through plant ventilating systems or by steam jets.

Open gas flames can be used in presses using high flashpoint (>300°F [149°C]) inks. The open flame is placed across the press at the delivery end. The paper quickly passes through or very close to the flame.

In every case where a gas flame is used for static elimination, the burner should be interlocked with the press so that the flame will be out when the press is stopped.

Electrically energized neutralizers are frequently used for static elimination on presses, especially rotary type presses. (See C.4.2, *Ionization*.) Ink spray from the ends of the rolls tends to accumulate on the ends of the neutralizers and heavy deposits may cause failure.

Higher operating speeds have resulted in the development of the enclosed ink fountain which provides a much safer press. The elimination of the flammable vapors by proper local ventilation is probably the best solution to eliminating fires on these presses. Conditioned air is conducted to the presses and exhausted from the paper as it passes from the printing cylinder. This not only assists in the rapid drying, but keeps the vapor concentrations below the lower flammable limits.

Slow speed presses do not present the fire hazard problem of high speed presses because inks used on flat-bed presses are usually high flashpoint. However, the static electricity problem from the production standpoint still exists. One of the most satisfactory treatments for adhesions to the tympan is the use of glycerine and acetic acid to dampen it.

A rotogravure press is an ideal static generator. A rubber roll is pressed with as much as four tons of pressure against a copper etched roll, which revolves in a heavy volatile ink. The paper passes between the two rolls. In a multicolored press there is a similar arrangement for each color. At high speeds the presses will often accumulate static charges sufficient to ignite flammable vapors over or near the ink fountains, if adequate ventilation is not provided.

The generation of static can sometimes be reduced by reducing the pressure between the rolls and changing the angle at which the paper enters the rolls to lighten its contact with each roll. Increasing paper and ink conductivity and pressroom air humidification also are effective in reducing static effects on rotogravure presses. For more complete control, however, a static eliminator or neutralizer, covering the full width of the web at the delivery side of each impression roller, is usually necessary.

C.11.5 Mixing and Blending Operations

Mixing, grinding, screening, or blending operations with solid nonconductive materials can generate static electricity. The pneumatic transport in ducts of finely divided nonconductive materials also can produce static. The degree of static hazard depends on the materials and the capacity of insulated conductive parts of the machines and ducts to accumulate sufficient charge to cause an incendive discharge.

Ignitable liquids, some having flash points of 100°F (38°C) or less, are mixed in churning, autoclaves or other vessels with various pigments, resins or similar materials in the manufacture of chemicals, paints, varnishes, lacquers, printing inks, and similar products. High speed agitation with solvents of high resistivity can produce high static potentials. These processes can be a severe fire and explosion hazard, depending on the flash point of the solvents, the amount involved, method of handling, the amount of ventilation and other factors. Static electricity is a potential ignition source and should be guarded against as described in Section 2.3, *Electrical*.

C.12 Plastics

C.12.1 Lacquers and Dopes

In the manufacture of lacquers and dopes, plastic powders or pellets are dissolved in solvents. The plastic materials and the solvents are usually nonconductive, but in the blending and mixing operation, static generation can be high, especially at the start of the operation. The charge generation can be reduced by using conductive solvents or by the addition of a conductive agent to nonconductive solvents.

C.12.2 Film Casting and Extrusion

In the manufacture of thin films the generation of static charge may be appreciable, especially when nonconductive dopes are employed. When conductive dopes are used, the hazard increases as the solvent is evaporated from the product, unless the finished product also is conductive. The static charge on the product can be reduced by ionizing the air in the immediate vicinity.

C.12.3 Reclamation of Waste

The process of reclaiming many types of waste or scrap material is similar to that of manufacturing lacquers and dopes. Similar methods as described previously may be used to reduce the hazard of static discharges.

C.13 Solvent Extraction Plants

The extraction of animal and vegetable fats by the use of hydrocarbon solvents creates severe fire and explosion hazards.

Safeguards against static electricity should be provided in the bulk solvent and unloading areas and the extraction building as detailed in Section 2.3, *Electrical*.

C.14 CLEANING OPERATIONS

C.14.1 Dry Cleaning

The dry cleaning process consists of removing dirt, grease, and other stains from wearing apparel, textiles, fabrics, and rugs. This process is accomplished by the use of ignitable or nonignitable nonaqueous liquid solvents. For the purpose of static electricity hazards, consideration need only be given to ignitable liquids with flash points at or above 100°F (38°C). Use of ignitable liquids with flash points below 100°F (38°C) is prohibited.

Commercial dry cleaning is done in closed machines (except for spotting operations). The cleaning operations are all likely to produce static charges on the insulating surfaces of the materials involved. These operations include immersing fabrics, some of them highly insulating, in various solvents, stirring and agitating them, and removing them from the solvent bath. The solvents themselves are good insulators and good generators of static electricity. These handling operations are also true of home dry cleaning. Methods of dry cleaning also include brushing, scouring, or spotting. As the cleaning solvents are conducive to static generation, appropriate safeguards are required.

The accumulation of static electricity on pulleys and belting and metal tops of spotting tables is also a potential hazard in this occupancy.

A free charge may exist on the surface of the solvent when in equipment such as washers or extractors (See C.6.1, *Free Charges on Surface of Liquid*.) Therefore, special consideration should be given to the generation and accumulation of static electricity in the handling of the fabrics, especially where fabrics are transferred from one piece of equipment to another.

Personnel performing dry cleaning operations also can accumulate a static charge. Control of such static is discussed C.3.2, *Static Accumulation by Personnel* and Section 2.3.5, *Clothing*.

C.14.2 Steam Cleaning

Wet steam escaping into the atmosphere can generate static electricity. Surfaces on which steam condenses may accumulate static, which can result in ignition if flammable vapor-air mixtures are present.

C.15 Spray Application Of Flammable And Combustible Materials

Ignitable solvent base coatings, water base coatings, and powder coatings are applied by a number of different methods employing electrostatic spray as described in Data Sheet 7-27, *Spray Application of Flammable and Combustible Materials*. With the exception of the airless spray system, there is little hazard from static discharges involved with these systems. The chief hazard from static discharges is associated with the improper handling of ignitable liquids employed with these systems. With the airless spray system static can accumulate both on the object being sprayed and on the spray gun.

C.16 Textiles

In the textile industry, the generation of static is mainly controlled by maintaining high relative humidity in the process areas, and grounding machinery. These methods are not wholly effective with synthetic fibers such as acetate yarn, nylon, orlon, dacron, vinyon, and others. These fibers are high dielectric and have low regain in moisture. Little friction or pressure is required to develop static. Rayon retains a higher percentage of moisture under similar conditions than cotton and wool.

The generation of static electricity in some cotton processes is primarily a production problem, which impairs the quality of the finished product, and causes an increase in waste and a reduction in output. Humidification at 50 to 60% is the most common and effective means of preventing unwanted electrification.

C.16.1 Cotton Gins

Experience has shown that the energy released by sparks from static accumulations has not been of sufficient magnitude to ignite loose lint, dust, or the cotton.

When the static charge on the cotton is of sufficient magnitude, the cotton will ball up in the gin stands and equipment. This results in a production problem and friction heat in the equipment. Fires due to friction are more likely and hot spots can cause fires in the bales.

The bonding and grounding of cotton gin equipment will not prevent or remove the static accumulation from the cotton being processed, although the generation of static may be minimized by the introduction of moisture or an anti-static agent.

C.17 Flammable Anesthetic Agents

Although nonflammable inhalation anesthetics are generally used today, cyclo-propane, divinyl ether, ethyl chloride, ethyl ether, and ethylene are still used occasionally in hospital operating rooms, emergency rooms, delivery rooms, and similar areas, to produce anesthesia. When mixed with air, oxygen or nitrous oxide, the mixture is easily ignited and can produce a violent explosion. A common source of ignition is the spark discharge from static accumulations on people or objects.

A *patient grounding point* should be provided in each anesthetizing area. This is a jack or a terminal bus installed on the wall near the head of the operating table. It provides a low impedance path and serves as a collection point for grounding the anesthetic machine, the surgical table, and other electrical appliances serving the area surrounding the patient.

A *room grounding point* also should be provided. This should consist of a highly conductive bare metal bar containing one or more Approved terminals for grounding each patient grounding point, the conductive floor, and all exposed metal structural surfaces in the room, such as gas pipes, water pipes, heating pipes, metal window sash, etc. The purpose of the room ground point is to ensure that all electrically conductive surfaces within reach of a patient are at the same electrical potential, not to exceed 5 millivolts.

C.18 Static Detection And Measurement

There are several devices available for detecting and measuring the magnitude of a static charge, including the field mill, electrostatic voltmeter, and the electrometer. There also are hand-held devices that indicate the presence of a static charge on objects at which they are pointed.

C.18.1 Field Mills

The field mill is a device containing a rotating shutter that alternately exposes a sensing electrode to the electrostatic field and to a field-free region. An alternating charge is induced on the electrode, amplified in an electronic circuit and shown on a meter. It is also known as a field intensity meter, electrostatic field meter, and generating voltmeter.

This device does not require contacting the charged object. Consequently, the field mill measures the field strength at its face only in volts per unit distance. It does not measure the voltage or field strength at a distant location. Accordingly, the meter reading may not accurately indicate the degree of hazard, since the field strength at the meter may be quite different from the field adjacent to the static charges.

C.18.2 Electrostatic Voltmeter

This instrument is used to measure the potential on a charged object to which it must be connected. It operates by electrostatic attraction between movable and stationary metal vanes. No current is passed to maintain deflection because one set of vanes (usually the stationary set) is highly insulated. Portable, accurately calibrated instruments are available in several ranges from 100 to 10,000 volts and more.

C.18.3 Electrometers

These instruments often are used for laboratory and field investigations of static electricity. They incorporate special input stages, which provide the high input resistance of 10^{14} ohms or more needed to avoid dissipation of the measured charges. Equally important, they have very low bias current (i.e., a self-generated current at the input which is typically less than 10^{-14} amperes). Although the maximum full scale range of the electrometer is usually only 10 or possibly 100 volts, static potential in the kilovolt range can be measured by attaching a calibrated high resistance voltage divider to the input. Electrometers can also measure charging current or integrated charge by means of suitable resistors or capacitors across the input or in a feedback configuration.

Electrometers are basically designed to contact the object being measured and of necessity draw some charge from the measured object. However, it is possible to make measurements without making contact by means of a probe, which acts as a capacitive divider and exposes the input terminal of the instrument to the electrostatic field of the charged object. It is not suited to continuous monitoring, but may be used for spot measurements.

C.18.4 Handheld Devices

There are several hand held instruments available. When pointed at a charged object, a meter on the instrument calibrated in volts will indicate the voltage of the charge on the object.

C.18.5 Electroscopes

The leaf deflection electroscope is a simple and sensitive device that demonstrates the presence or absence of a static charge by the repulsion of its leaves when the device is charged. Only units intended as portable dosimeters for ionizing radiation and one or two classroom demonstration models are available.

C.18.6 Neon Lamps

A small neon lamp or a fluorescent tube will light up feebly when one terminal is grounded (or held in the hand) and the other makes contact with any surface that carries a potential of 70 volts or more. The lamp will glow as the surface is discharged through the lamp.