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# NFPA 77
# Static Electricity
## 1988 Edition

NFPA®

National Fire Protection Association Batterymarch Park, Quincy, MA 02269

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### Policy Adopted by NFPA Board of Directors on December 3, 1982

The Board of Directors reaffirms that the National Fire Protection Association recognizes that the toxicity of the products of combustion is an important factor in the loss of life from fire. NFPA has dealt with that subject in its technical committee documents for many years.

There is a concern that the growing use of synthetic materials may produce more or additional toxic products of combustion in a fire environment. The Board has, therefore, asked all NFPA technical committees to review the documents for which they are responsible to be sure that the documents respond to this current concern. To assist the committees in meeting this request, the Board has appointed an advisory committee to provide specific guidance to the technical committees on questions relating to assessing the hazards of the products of combustion.

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### Statement on NFPA Procedures

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# NFPA 77

## Recommended Practice on

# Static Electricity

## 1988 Edition

This edition of NFPA 77, *Recommended Practice on Static Electricity*, was prepared by the Technical Committee on Static Electricity, and acted on by the National Fire Protection Association, Inc. at its Annual Meeting held May 16-18, 1988, in Los Angeles, California. It was issued by the Standards Council on June 8, 1988 with an effective date of June 28, 1988, and supersedes all previous editions.

The 1988 edition of this document has been approved by the American National Standards Institute.

Changes other than editorial are indicated by a vertical rule in the margin of the pages on which they appear. These lines are included as an aid to the user in identifying changes from the previous edition.

## Origin and Development of NFPA 77

NFPA committee activity in this field was initiated in 1936 and a progress report was presented to the Association in 1937. A revised text was tentatively adopted in 1941 and, with further revisions, was finally adopted in 1946.

Revised editions have subsequently been adopted by the Association in 1950, 1961, 1966, 1972, 1977, 1982, and 1988.

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# Contents

# NFPA 77

## Recommended Practice on

# Static Electricity

## 1988 Edition

NOTICE: An asterisk (*) following the number or letter designating a paragraph indicates explanatory material on that paragraph in Appendix A.

Information on referenced publications can be found in Chapter 9.

## Chapter 1 General

### 1-1 Purpose.

**1-1.1** The purpose of this recommended practice is to assist in reducing the fire hazard of static electricity by presenting a discussion of the nature and origin of static charges, the general methods of mitigation, and recommendations in certain specific operations for its dissipation.

**1-1.2** Static electricity is often the ignition source for an ignitable mixture, an operating problem in industry, or an annoyance to some individuals.

### 1-2 Scope.

**1-2.1** This publication covers methods for the control of static electricity for the purpose of eliminating or mitigating its fire hazard, except as provided in 1-2.2 and 1-2.3 below.

**1-2.2** The prevention and control of static electricity in hospital operating rooms or in areas where flammable anesthetics are administered are not covered by this publication but are covered in NFPA 99, *Standard for Health Care Facilities.*

**1-2.3** Lightning is not covered by this publication but is covered in NFPA 78, *Lightning Protection Code.*

### 1-3 Definitions. (*See also Appendix B.*)

**Approved.** Acceptable to the "authority having jurisdiction."

NOTE: The National Fire Protection Association does not approve, inspect or certify any installations, procedures, equipment, or materials nor does it approve or evaluate testing laboratories. In determining the acceptability of installations or procedures, equipment or materials, the authority having jurisdiction may base acceptance on compliance with NFPA or other appropriate standards. In the absence of such standards, said authority may require evidence of proper installation, procedure or use. The authority having jurisdiction may also refer to the listings or labeling practices of an organization concerned with product evaluations which is in a position to determine compliance with appropriate standards for the current production of listed items.

**Authority Having Jurisdiction.** The "authority having jurisdiction" is the organization, office or individual responsible for "approving" equipment, an installation or a procedure.

NOTE: The phrase "authority having jurisdiction" is used in NFPA documents in a broad manner since jurisdictions and "approval" agencies vary as do their responsibilities. Where public safety is primary, the "authority having jurisdiction" may be a federal, state, local or other regional department or individual such as a fire chief, fire marshal, chief of a fire prevention bureau, labor department, health department, building official, electrical inspector, or others having statutory authority For insurance purposes, an insurance inspection department, rating bureau, or other insurance company representative may be the "authority having jurisdiction." In many circumstances the property owner or his designated agent assumes the role of the "authority having jurisdiction"; at government installations, the commanding officer or departmental official may be the "authority having jurisdiction."

**Bonding.** The process of connecting two or more conductive objects together by means of a conductor.

**Grounding (Earthing).** The process of connecting one or more conductive objects to the ground, and is a specific form of bonding. The words Bonded or Grounded, as they are used in the text, must be understood to mean either that a bond or ground as defined has been deliberately applied, or that an electrically conductive path having a resistance adequately low for the intended purpose (usually $10^6$ ohms or less) is inherently present by the nature of the installation.

**Ignitable Mixture.** A vapor-air, gas-air, dust-air mixture or combinations of these mixtures which can be ignited by a static spark.

**Labeled.** Equipment or materials to which has been attached a label, symbol or other identifying mark of an organization acceptable to the "authority having jurisdiction" and concerned with product evaluation, that maintains periodic inspection of production of labeled equipment or materials and by whose labeling the manufacturer indicates compliance with appropriate standards or performance in a specified manner.

**Listed.** Equipment or materials included in a list published by an organization acceptable to the "authority having jurisdiction" and concerned with product evaluation, that maintains periodic inspection of production of listed equipment or materials and whose listing states either that the equipment or material meets appropriate standards or has been tested and found suitable for use in a specified manner.

NOTE: The means for identifying listed equipment may vary for each organization concerned with product evaluation, some of which do not recognize equipment as listed unless it is also labeled. The "authority having jurisdiction" should utilize the system employed by the listing organization to identify a listed product.

**Should.** Indicates a recommendation or that which is advised but not required.

**Static Electricity.** An electrical charge that is significant only for the effects of its electrical field component and that manifests no significant magnetic field component.

**Static Spark.** An impulsive discharge of electricity across a gap between two points not in contact.

### 1-4 Introduction.

**1-4.1** Static electrification and the various effects that result from the positive and negative charges so formed may constitute a fire or explosive hazard. The generation of static electricity cannot be prevented absolutely, because its intrinsic origins are present at every interface.

**1-4.2** The development of electrical charges may not be in itself a potential fire or explosion hazard. There must be a discharge or sudden recombination of separated positive and negative charges. In order for static to be a source of ignition, four conditions must be fulfilled:

(a) There must first of all be an effective means of static generation,

(b) There must be a means of accumulating the separate charges and maintaining a suitable difference of electrical potential,

(c) There must be a spark discharge of adequate energy, and

(d) The spark must occur in an ignitable mixture.

**1-4.3** The accumulation of static charges may be prevented under many circumstances by grounding or bonding, by humidification, or by ionization. These means and their functions are discussed in Chapter 3.

**1-4.4** Common sources of static electricity include:

(a) Pulverized materials passing through chutes or pneumatic conveyors,

(b) Steam, air, or gas flowing from any opening in a pipe or hose, when the steam is wet or the air or gas stream contains particulate matter,

(c) Nonconductive power or conveyor belts in motion,

(d) Moving vehicles, and

(e) Motions of all sorts that involve changes in relative position of contacting surfaces, usually of dissimilar liquids or solids.

**1-4.5** The object of most static-corrective measures is to provide a means whereby charges separated by whatever cause may recombine harmlessly before sparking potentials are attained, or to avoid spark gaps where harmful discharges could occur.

**1-4.6** If hazardous static conditions cannot be avoided in certain operations, means must be taken to assure that there are no ignitable mixtures at points where sparks may occur.

## 1-5 General.

**1-5.1** To the average person the words "static electricity" may mean either a noise in the radio receiver which interferes with good reception or the electric shock experienced when touching a metal object after walking across a carpeted floor or sliding across the plastic seat cover in an automobile. Some people also have experienced mysterious crackling noises and a tendency for some of their clothing to cling or stick tightly together when wool, silk, or synthetic fiber garments are worn. Nearly everyone recognizes that these phenomena occur mainly when the atmosphere is very dry. To most people they are simply an annoyance.

**1-5.2** The word "electricity" is derived from the ancient Greek word "elektron" — meaning amber — for it was with this substance that the phenomenon of electrification was first observed. For centuries "electricity" had no other meaning than the property exhibited by some substances, after being rubbed with a material like silk or wool, of being able to attract or repel lightweight objects. Stronger electrification accompanied by luminous effects and small sparks was first observed about 300 years ago by von Guericke. In comparatively recent times, when the properties of flowing electricity were discovered, the word "static" came into use as a means of distinguishing the old from the new. The implication that such electricity is always at rest is erroneous; it is when it ceases to rest that it causes the most concern.

**1-5.3** For the sake of simplicity, one may imagine electricity to be a weightless and indestructible fluid that can move freely through some substances, such as metals, that are called "conductors," but can flow with difficulty or not at all through or over the surface of a class of substances called "nonconductors" or "insulators." This latter group includes: gases, glass, rubber, amber, resin, sulfur, paraffin, and most dry petroleum oils and many plastic materials. When electricity is present on the surface of a nonconductive body, where it is trapped or prevented from escaping, it is called static electricity. Electricity on a conducting body that is in contact only with nonconductors is also prevented from escaping and is therefore nonmobile or "static." In either case, the body on which this electricity is evident is said to be "charged."

**1-5.4** The charge may be either positive ( + ) or negative (-). At one time it was thought that the two charges were two kinds of electricity and that in a neutral (uncharged) body they were present in exactly equal amounts. Now it is known that there is actually only one kind of electricity, although it is described by many adjectives. It is manifested when some force has abnormally separated a few of its positive and negative constituents. These entities are components of all atoms, the outer electrons (-) and the inner (nuclear) protons ( + ). Curiously, a surface that has an excess or deficiency of one electron in every 100,000 atoms is very strongly charged.

**1-5.5** It is true, however, that in a neutral or uncharged body the two entities are present in exactly equal amounts. Work is required to separate positive and negative charges. Electricity, therefore, is sometimes referred to as a form of energy produced by expenditure of energy in some other form, such as mechanical, chemical, or thermal. Likewise, when electrical energy (a better term) is expended, its equivalent appears in one of these other forms.

**1-5.6** Electrons are free to move from one molecule to another in conductors but the proton, in the nucleus of the atom, cannot move appreciably unless the atom moves. Therefore, in solids, only the electrons are mobile; in gases and liquids both are free to move.

**1-5.7** The stable structure of the atom shows that unlike charges attract; and, conversely, like charges repel. It follows that a separated charge will be self-repellent and will reside only on the surface of a charged body. If the body were a perfect insulator or perfectly insulated, the charge would remain indefinitely. However, there are no perfect insulators and isolated charges soon leak away to join their counterparts and thus bring about neutralization, the normal state. (*See also Section 3-3.*)

**1-5.8** Static electricity then is the set of phenomena associated with the appearance of an electric charge on the surface of an insulator or insulated conductive body. It is "generated" usually by the expenditure of mechanical work, although we must remember that in this sense generated means "liberated" or made alive — electricity cannot be created. Somewhere, possibly "grounded" but as close as conditions will allow, there will be an exactly equal opposite charge — its counterpart. This concept is extremely important.

## 1-6* Generation and Storage.

### 1-6.1 Generation.

**1-6.1.1 Introduction.** Like charges repel each other and unlike charges attract. The charge on the surface of an insulator can thus attract an equal and opposite charge on the nearest surface of any conducting body close to it. A companion charge of opposite polarity will be repelled to the more remote side. This is the process called induction. The charge on the near side is said to be "bound"; the repelled charge on the opposite side is "free," and may be dissipated by momentarily providing a path to earth. If the conducting body is now moved away from the originally charged body, the bound charge is now freed and will redistribute itself over the whole surface of the conducting body. In turn, it can be released in the form of a spark.

**1-6.1.2 Contact/Separation (Frictional) Charging.** When two substances of different composition are brought into contact, one of the substances will surrender some of the electrons from its atoms to the other along the contact surface. Although the total (net) charge upon the two substances remains unchanged (and may be zero), the redistribution of charge resulting from this transfer of electrons results in the formation of an "electrical double layer" along the contact surface. One substance will have an increased abundance of electrons (and be negatively charged) while the other will be somewhat depleted of electrons (and be positively charged). Since these equal and opposite charges are strongly attracted to each other, they remain intimately related to the opposing surfaces and are not externally sensible so long as the surfaces remain in contact. If the substances are nonconductive and are pulled apart, however, much of the charge disparity will remain with the individual substances, resulting in one being charged positively and one negatively. This charging mechanism is enhanced by increased speed of separation, by lowered conductivity of the substances, and by increased disparity in work function of the substances.

**1-6.1.3 Ion Bombardment.** The surface of a substance that is subjected to bombardment by an ion shower (such as originates at a corona point) will become charged by attachment of the ions and/or by surrender of charge to the surface by the ions. Charging by this mechanism is referred to as "bombardment charging."

**1-6.1.4 Contact.** When an uncharged object is brought into contact with another object that is charged, some charge will be transferred to the previously uncharged object.

**1-6.2** Whereas a spark from the surface of an insulator can release a charge from only a small area, all the charge on the conducting body can be released in a single spark. Thus, in many situations, induced charges are far more dangerous than the initially separated ones upon which they are dependent.

**1-6.3** In effect, a metal plate in close proximity to a charged surface can be considered one plate of a capacitor, and its ability to store energy is described as its capacitance. When a potential difference is applied between the two plates of a capacitor, electricity can be stored. In some instances one of the plates is the earth, the insulating medium is the air, and the other plate is some body or object insulated from the earth to which the charge has been transferred by induction or otherwise. When a conducting path is made available, the stored energy is released (the capacitor is discharged), possibly producing a spark. The energy so stored and released by the spark is related to the capacitance (C) and the voltage (V) in accordance with the following:

$$\text{Energy} = \frac{C\,(V)^2}{2}$$

(*See Appendix B for a discussion of terms.*)

**1-6.4** If the object close to the highly charged nonconductor is itself a nonconductor, it will be polarized; that is, its constituent molecules will be oriented to some degree in the direction of the lines of force since their electrons have no true migratory freedom. Because of their polarizable nature, insulators and nonconductors are often called dielectrics. Their presence as separating media enhance the accumulation of charge.

## 1-7 Ignition Energy.

**1-7.1** The ability of a spark to produce ignition is governed largely by its energy, which will be some fraction of the total stored energy.

**1-7.2** Tests have shown that saturated hydrocarbon gases and vapors require approximately 0.25 millijoule of discharge energy for spark ignition of optimum mixtures with air. Unsaturated hydrocarbons may have lower minimum ignition energies. (*See Table 1-7.2.*) It has been shown further that sparks arising from potential differences of less than 1500 volts are unlikely to be hazardous in saturated hydrocarbon gases because of the short gap and heat loss to the terminals.

**Table 1-7.2**
**Approximate Minimum Ignition Energy**

| | millijoule |
|---|---|
| methane | 0.29 |
| propane | 0.25 |
| cyclopropane | 0.18 |
| ethylene | 0.08 |
| acetylene | 0.017 |
| hydrogen | 0.017 |

**1-7.3** Tests have shown that dusts and fibers usually require discharge energy of one or two magnitudes greater than that of common gases and vapors for spark ignition of optimum mixtures with air. (The ignition energy requirement diminishes rapidly with decreased particle size of dusts.)

**1-7.4 Hybrid Mixtures.** When two or more flammable materials in different phases, for example, a dust plus a vapor, are present in a mixture, the mixture is known as "hybrid." Tests have shown that admixture of a flammable gas to a dust suspension can greatly lower the ignition energy of the dust, even if the gas is present at below its lower flammable limit. The mixture may be flammable even if both components are below their respective lower flammable limits. The hybrid mixture may be formed by vapor desorption (such as in resin product receivers), reaction with atmospheric moisture (such as aluminum propoxide handling), or by handling a dust in a flammable vapor atmosphere (such as adding a dust or powder to a flammable liquid). In such instances, the hybrid mixture could be ignited at an energy level approaching that of the most easily ignited component.

**1-7.5** Ignition energy is reduced by an increase in oxygen concentration relative to that of air.

**1-8 Summary.**

**1-8.1** In summarizing, static electricity will be manifest only where highly insulated bodies or surfaces are found. If a body is "charged" with static electricity, there will always be an equal and opposite charge produced. If a hazard is suspected, the situation should be analyzed to determine the location of both charges and to see what conductive paths are available between them.

**1-8.2** Tests of the high-resistance paths should be made with an applied potential of 500 volts or more, in order that a minor interruption (paint or grease-film or airgap) will be broken down and a correct reading of the instrument obtained.

**1-8.3** Resistances as high as 10,000 megohms will provide an adequate leakage path in many cases; when charges are generated rapidly, however, a resistance as low as 1 megohm ($10^6$ ohms) might be required.

**1-8.4** Where bonds are applied,'they should connect the bodies on which the two opposite charges are expected to be found.

## Chapter 2 The Hazards of Static Electricity

**2-1 Static Electricity as an Ignition Source.**

**2-1.1 Flammable and Combustible Liquids.** Static is generated when liquids move in contact with other materials. This occurs commonly in operations such as flowing them through pipes, and in mixing, pouring, pumping, filtering, or agitating. Under certain conditions, particularly with liquid hydrocarbons, static may accumulate in the liquid. If the accumulation is sufficient, a static spark may occur. If the spark occurs in the presence of a flammable vapor-air mixture, an ignition may result. Therefore, steps should be taken to prevent the simultaneous occurrence of the two conditions.

**2-1.2 Gases.** When 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 object will charge the latter unless the object is grounded or bonded to the discharge pipe. If the accumulation is sufficient, a static spark may occur. If the spark occurs in the presence of a flammable vapor-air mixture, an ignition may result. Where a static spark and a flammable vapor-air mixture may occur simultaneously, suitable preventive measures are required to avoid ignition.

**2-1.3 Dusts and Fibers.** Generation of static charge is commonly observed during handling and processing of dusts and fibers in industry. There are recorded instances where ignition of a combustible dust cloud or layer is attributed to the static electrical discharge. In all instances in which static electricity has been authentically established as the cause of ignition, the spark occurred between an insulated conductor and ground. It has not been verified experimentally that a dust cloud can be ignited by static discharge within itself.

**2-2 Personnel Hazards of Static Electricity.**

**2-2.1 The Human Body.** The human body is an electrical conductor and in dry atmospheres frequently accumulates a static charge resulting in voltages as high as several thousand volts. This charge is generated by contact of the shoes with floor coverings, or by participation in various manufacturing operations.

**2-2.2 Clothing.**

**2-2.2.1** Under many conditions, the shoes and clothing of workers can be conductive enough to drain away static charges as fast as they are generated.

**2-2.2.2** Although silk and some synthetic fibers are excellent insulators, and undergarments made from them exhibit static phenomena, there is no conclusive evidence to indicate that wearing such undergarments constitutes a hazard.

**2-2.2.3** Outergarments, on the other hand, can build up considerable static charges when moved away from the body, or removed entirely. Under many conditions this effect constitutes little hazard. However, for some materials and/or low humidity conditions an electrostatic ignition source may exist.

**2-2.2.4** The removal of outer garments is particularly dangerous in work areas such as hospital operating rooms, explosive manufacturing facilities, and similar occupancies where there may be flammable or explosive atmospheres that are ignitable with low electrical energy. Outergarments used in these areas should be suitable for the work area. NFPA 99, *Health Care Facilities*, provides information on test methods for evaluating the antistatic performance of wearing apparel.

2-2.2.5 In liquid oxygen filling plants, vapor from cooled gas may permeate the employee's clothing, rendering it flammable. A static charge accumulating on the person can cause ignition. This can be prevented by the use of conductive footwear and conductive floors.

**2-2.3 Hazardous Occupancies.** Where ignitable mixtures exist there is a possible ignition potential from the charged human body, and means to prevent accumulation of static charge on the human body may be necessary. Steps to prevent such accumulations may include:

(a) Avoiding the wearing of rubbers, rubber boots, rubber-soled shoes, and nonconductive synthetic-soled shoes.

(b) Providing conductive floors and conductive footwear.

**2-2.4 Discomfort and Injury.** Static shock can result in discomfort and, under some circumstances, injury to workers due to involuntary reaction. The discharge in itself is not dangerous to humans, but it may cause an involuntary reaction that results in a fall or entanglement with moving machinery. If charge accumulation cannot be avoided, and there are no flammable gases or vapor present, consideration should be given to the various methods by which contact with metal parts can be eliminated. Such methods would include, among others, the use of nonmetallic hand rails, insulated doorknobs, and other nonconducting shields.

## 2-3 Process Hazards of Static Electricity.

### 2-3.1 Mixing and Blending Operations.

**2-3.1.1** Mixing, grinding, screening, or blending operations with solid nonconductive materials, as well as the pneumatic conveying of finely divided nonconductive materials, can generate static electricity. The degree of static hazard is influenced by the ability of the materials to generate and hold a charge and on the capacitance of insulated conductive parts of the machines and ducts to accumulate sufficient charge to cause an incendive discharge. (*See Section 7-4.*)

**2-3.1.2** Flammable liquids are mixed in churns or autoclaves with various pigments, resins, or similar materials in the manufacture of paints, varnishes, lacquers, printing inks, and similar products. This process can be a severe fire and explosion hazard depending upon the flashpoint of the solvents, the amount involved, method of handling, the amount of ventilation, and other factors. Static electricity is a potential ignition source and can be guarded against. (*See Chapter 4.*)

**2-3.2 Cotton Gins.** 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 frictional heat in the equipment. Experience has shown that the amount of energy released by sparks due to static accumulations has not been of sufficient magnitude to ignite loose lint, dust, or cotton. (*See Section 5-4.*)

**2-3.3 Coating, Spreading, and Impregnating.** In each of these operations the material to be processed usually is unwound from a roll at the feed end of the machine, where 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 and then under a doctor knife, then 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. If flammable liquids are employed, the static electricity may be a source of ignition. (*See Section 7-2.*)

**2-3.4 Belts.** Some types of belts frequently exhibit static generation, which may or may not warrant corrective measures, depending on circumstances. (*See Section 7-1.*)

**2-3.5 Drycleaning.** Commercial drycleaning operations are in closed machines except for spotting operations. The operations employed — immersing fabrics, some of them highly insulating, in various solvents which are themselves good insulators and good generators of static electricity, stirring and agitating them, and removing them from the solvent bath — are all likely to produce static charges on the insulating surfaces of the materials involved. If flammable liquids are employed, the static electricity may be a source of ignition. (*See NFPA 32, Drycleaning Plants.*)

### 2-3.6 Printing and Lithographing.

**2-3.6.1** In the printing and lithographing industries static electricity is a frequent, annoying, and often expensive source of trouble from the production standpoint. Where flammable inks and solvents are used in the process, static may create a fire or explosion hazard. (*See Section 7-3.*)

**2-3.6.2** In practice, sheets charged with static electricity have an attraction for other objects, and this often causes difficulty in controlling the sheets or webs and sometimes results in tearing of the webs. It may also 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 may also be damaged by the attraction of dust particles and loose paper fibers to the paper.

**2-3.7 Spray Finishing.** The application of paint, varnishes, enamels, lacquers, and other finishes by spray finishing equipment may cause a static charge to accumulate on the object being sprayed and the spray gun. If flammable liquids are employed, the static electricity may be a source of ignition. (*See NFPA 33, Spray Application Using Flammable and Combustible Materials.*)

**2-3.8 Steam Jets.** Wet steam escaping into the atmosphere can generate static electricity that can accumulate on any insulated object in the area. If flammable vapor-air mixtures are likely to be present, the discharge of static electricity may become a source of ignition. (*See Section 7-6.*)

**2-3.9 Explosive Manufacturing.** Primary explosives, mercury fulminate and tetryl for example, if in the form of a dust, are readily detonated by static spark discharge. Steps necessary to prevent accidents from static electricity in explosive manufacturing operations and storage areas vary considerably with the static sensitivity of the material being handled.

## Chapter 3 Control of Ignition Hazards

**3-1 Static Control.** Ignition hazards from static electricity can be eliminated by removing the ignitable mixture from the area where static may be discharged as sparks, controlling the amount or speed of charge generation, or relaxing a charge after it has been generated.

**3-2 Control of Static Generation.** Since static is generated whenever two dissimilar materials are in relative motion to each other, a slowing down of this motion will reduce the rate of the generation of static electricity. For example, a low conductivity material flowing through pipes, ducts, filters, and the like will generate static electricity. If the material flows at a low enough rate, a hazardous level of static will not be generated. Frequently this means of static control is not commercially acceptable because of slower production.

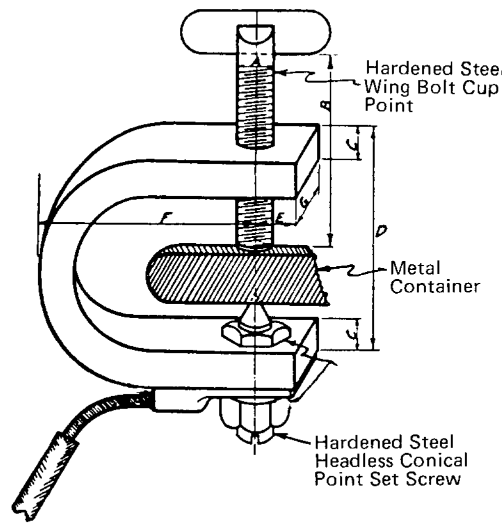



**Figure 1** Typical Pressure-type Ground Clamp.

### 3-3 Charge Relaxation (Dissipation).

### 3-3.1 Bonding and Grounding.

**3-3.1.1** A conductive object may be grounded directly or by bonding it to another conductive object that is already connected to the ground. Some objects are inherently bonded or inherently grounded by their contact with the ground. Examples are underground piping or large storage tanks resting on the ground.

**3-3.1.2** Bonding is done to minimize potential differences between conductive objects. Likewise, grounding is done to minimize potential differences between objects and the ground.

**3-3.1.3** The minimum size of wire is dictated by mechanical strength rather than by current-carrying capacity. Flexible conductors should be used for bonds that are to be connected and disconnected frequently. To prevent the accumulation of static electricity the resistance need not be less than 1 megohm and in most cases may be even higher. To protect electrical power circuits the resistance must be low enough to ensure operation of the fuse or circuit breaker under fault conditions. Any ground that is adequate for power circuits or lightning protection is more than adequate for protection against static electricity.

**3-3.1.4** Conductors may be insulated or uninsulated. Some prefer uninsulated conductors so that defects can be easily spotted by visual inspections. If insulated, the conductor should be checked for continuity at regular intervals, depending on experience.

**3-3.1.5** Connections may be made with pressure-type ground clamps, brazing, welding, battery-type clamps, or magnetic or other special clamps that provide metal-to-metal contact. (*See Figures 1, 2, and 4.*)

**3-3.1.6** The resistance between a grounded object and the soil is made up of the resistance of the ground wire itself and the resistance of the ground electrode (ground rod) to the soil. Most of the resistance in any ground connection is in the contact of the ground electrode with the soil. The ground resistance is quite variable as it depends upon the area of contact, the resistivity of the soil, and the amount of moisture.

### 3-3.2 Humidification.

**3-3.2.1** It is a matter of common experience that manifestations of static electricity — e.g., the sparks that an individual may experience from walking across a rug — are more intense in periods of dry weather than they are when a moist atmosphere prevails. From such experience has arisen the erroneous popular belief that static generation is controlled by weather. Actually, the generating mechanism is not influenced by weather, but weather does have a marked effect on whether a generated charge leaks away so fast that no observable accumulation results, or whether it can build up to produce the commonly recognized sensory manifestations.

**3-3.2.2** In Chapter 1, materials were loosely described as "conductors," as distinguished from "nonconductors" or "insulators," and it was stated that, since there is no perfect insulator, isolated charges of static electricity eventually dissipate. Anything that could be relied upon to impart conductivity to an insulating body would thus become a means of dissipating static charges.

**3-3.2.3** Most of the commonly encountered insulating materials, such as fabric, wood, paper, films, concrete, or masonry, contain a certain amount of moisture in equilibrium with the air in the surrounding atmosphere. This moisture content varies depending on weather, and to a large measure it controls the conductivity of the material, and hence its ability to prevent the escape of static electricity. The conductivity of these materials is controlled, not by the absolute water content of the air, but by its relative humidity. This figure, as ordinarily recorded in weather reports and comfort charts, is the ratio of the partial pressure of the moisture in the atmosphere to the partial pressure of water at the prevailing atmosphere temperature. Under conditions of high relative humidity — 50 percent or higher — the materials in question will reach equilibrium conditions containing enough moisture to make the conductivity adequate to prevent static accumulations.

**3-3.2.3.1** At the opposite extreme, with relative humidities of 30 percent or less, these same materials may dry out and become good insulators, and static manifestations become noticeable. There is no definite boundary line between these two conditions.

**3-3.2.4** It should be emphasized that the conductivity of these materials is a function of relative humidity. At any constant moisture content, the relative humidity of an atmosphere decreases as the temperature is raised and vice versa. In cold weather, the absolute humidity of the outdoor atmosphere may be low, even though the relative humidity may be high. When this same air is brought indoors and heated, the relative humidity becomes very low. As an example, a saturated atmosphere at an outdoor temperature of 30°F (-1°C) would have a relative humidity of only a little over 20 percent if heated up to a room temperature of 70°F (21°C). This phenomenon is responsible for the previously mentioned common belief that static generation is always more intense during winter weather. The static problem is usually more severe during this period because static charges on a material have less opportunity to dissipate when relative humidities are low.

**3-3.2.5** Humidifying the atmosphere has proved to be a solution to static problems in some special circumstances, as where static has resulted in the adhesion or repulsion of sheets of paper, layers of floss, fibers, and the like. It is usually stated that a relative humidity of about 50 percent or higher will avoid such difficulties.

**3-3.2.5.1** Unfortunately, it is not practical to humidify all occupancies in which static might be a hazard. It is necessary to conduct some operations in an atmosphere having a low relative humidity to avoid deleterious effects on the materials handled. High humidity can also cause intolerable comfort conditions in operations where the dry bulb temperature is high. On the other hand, a high humidity may advantageously affect the handling properties of some materials, thus providing an additional advantage.

**3-3.2.5.2** In some cases localized humidification produced by directing a steam jet onto critical areas may provide satisfactory results without the need for increasing the humidity in the whole room (*see 7-2.6 and Section 7-6*).

**3-3.2.6** It does not follow that humidification is a cure for all static problems. Some insulators are not susceptible to moisture absorption from the air, and high humidity will not noticeably decrease the resistivity. Notable examples are the uncontaminated surfaces of some plastics and the surface of petroleum liquids. Such surfaces are capable of accumulating static charges even though the atmosphere may have relative humidity of up to 100 percent.

**3-3.2.7** In summary, humidification may be a cure for static problems where the surfaces on which the static electricity accumulates are those materials that can absorb moisture and that are not abnormally heated. For heated surfaces, and for static on the surface of oils and some other liquid and solid insulating materials, high humidity will not provide a means for draining off static charges, and some other solution must be sought.

**3-3.3 Increasing Conductivity.**

**3-3.3.1** Electrostatic charges may accumulate on the surfaces of low conductivity materials. By increasing the conductivity, i.e., lowering the resistivity, these charges can be relaxed before they can accumulate to a hazardous level.

**3-3.3.2** In solid material, it may be possible to add a conductive material to increase the conductivity. For instance, carbon black has been added to some plastics to increase their conductivity.

**3-3.3.3** In liquid fuels, conductivity additives have been used for controlling charge accumulation. These are polar materials, blended into fuels, usually at low concentrations. Conductivity levels greater than 50 picoseimens/meter (pS/m)* at use temperature are generally considered nonhazardous.

**3-3.3.3.1** The effect of conductivity additives decreases with decreasing temperature. It is important that enough additive be used to assure satisfactory conductivity at the lowest product use temperature.

**3-3.3.3.2** It is important to note that conductivity additives do not prevent the generation of static electricity. They allow rapid charge relaxation, i.e., the recombining with charges of opposite polarity. The use of conductivity additives must be in conjunction with bonding and grounding to provide a complete electrical path for charge relaxation.

**3-3.4 Ionization.**

**3-3.4.1 General.** Under certain circumstances air may become sufficiently conducting to dissipate static charges. In the use of all static neutralizers, one must consider certain engineering problems such as environmental conditions (dust, temperature, etc.), and positioning of the device in relation to the stock, machine parts, and personnel. It is important to note that these control devices do not prevent the generation of static charges (*see 1-4.1*); they utilize ionization of air (or other gas) to reduce the charge to a controlled level.

**3-3.4.2 Inductive Neutralizer (Static Comb).**

**3-3.4.2.1** A static charge on a conductive body is free to flow, and on a spherical body in space it will distribute itself uniformly over the surface. If the body is not spherical, the self-repulsion of the charge will make it concentrate on the surfaces having the least radius of curvature.

**3-3.4.2.2** If the body is surrounded by air (or other gas) and the radius of curvature is reduced to almost zero, as with a sharp needle point, the charge concentration on the point can produce ionization of the air, rendering it conductive. Whereas a surface of large diameter can receive and hold a high voltage, the equivalent surface equipped with a sharp needle point can hold only a small charge before the leakage rate equals the rate of generation. The

* $1 pS/m = 1 \times 10^{-12} \hat{=} {}^{-1} m^{-1}$

induced charge in a grounded needle when placed in the vicinity of a charged body may thus cause corona ionization of the air and allow the charged body to dissipate its charge to ground. The threshold for this effect and its efficiency depend on many factors such as relative geometry, charge density on the body, and speed of movement relative to the needle. The basic principle has led to various designs of inductive neutralizers.

**3-3.4.2.3** A "static comb" is a metal bar equipped with a series of needle points. Another variation is a metal wire surrounded with metallic tinsel.

**3-3.4.2.4** The charge density on a nonconductor is an absolute quantity but it may vary with position. The electric field associated with this charge may be used to obtain qualitative "voltage" measurements proportional to the charge when made in any fixed geometry. The measurement is of great utility in the design and placement of inductive and other neutralizers. On a moving belt, the apparent voltage is an averaged value. By measuring apparent voltage after the neutralizer, optimum placement may be found.

**3-3.4.2.5** When inductive neutralizers are used for moving belts (*see Section 7-1 for power belts, Section 7-2 for fabrics, and Section 7-3 for paper*), as shown in Figure 6, the threshold for operation has been found to correspond to an apparent 5 kV on the belt. The measurement is made ahead of the neutralizer, away from grounded objects such as rollers, using a field-mill or other device placed about 1 in. (25 mm) from the charged surface. If problems are experienced under such conditions, the inductive bar may be used in conjunction with other devices (*see 3-3.4.3 and 3-3.4.4 in particular*).

**3-3.4.3 Electrical Neutralizer.**

**3-3.4.3.1** The electrical neutralizer is a line-powered high voltage device that is an effective means for removing static charges from materials like cotton, wool, silk, or paper in process, manufacturing, or printing. It produces a conducting ionized atmosphere in the vicinity of the charged surfaces. The charges thereby leak away to some adjacent grounded conducting body.

**3-3.4.3.2** Electrical neutralizers should not be used where flammable vapors, gases, or dust may be present unless approved specifically for such locations.

**3-3.4.4 Radioactive Neutralizer.**

**3-3.4.4.1** Another method for dissipating static electricity involves the ionization of air by radioactive material. Such installations require no redesign of existing equipment. The fabrication and distribution of radioactive neutralizers are licensed by the US Nuclear Regulatory Commission (or Agreement State Licensing Agency), which is responsible for the health and safety of the general population.

**3-3.4.4.2** Radioactive substances are not of themselves a potential ignition source; hence, the location of such sources for purposes of static dissipation need not be restricted on the basis of possible flammability of the surrounding atmosphere. However, if the radiation source is some sort of line-powered device, the location of the equipment must be restricted in the same manner as for any other electrical device, in accordance with NFPA 70, *National Electrical Code®*.

**3-3.4.4.3** The use of apparent voltages indicates that where this exceeds about 20 kV (*see 3-3.4.2.4*), the efficiency is reduced significantly, depending on belt speed. In this case, the use of an inductive neutralizer ahead of the radioactive neutralizer has proved effective.

**3-3.4.5 Open Flame.** Ionization of the air can also be obtained by an open flame. (*See 7-3.4.6.*)

**3-3.4.6** Ionization by any of the methods described in 3-3.4 is particularly adaptable to the processes discussed in Sections 7-1, 7-2, and 7-3.

**3-4 Control of Ignitable Mixtures by Inerting, Ventilation, or Relocation.**

**3-4.1** Despite planned efforts to prevent accumulation of static charges, which should be the primary aim of good design, there are many operations involving the handling of nonconductive materials or nonconductive equipment that do not lend themselves to this built-in solution. It may then be desirable, or essential, depending on the hazardous nature of the materials involved, to provide other measures to supplement or supplant static dissipation facilities, such as:

**3-4.1.1** Where the normally ignitable mixture is contained within a small enclosure, such as a processing tank, an inert gas may be used effectively to make the mixture nonflammable. (*See NFPA 69, Standard on Explosion Prevention Systems.*) When operations are normally conducted in an atmosphere above the upper flammable limit it may be practicable to apply the inert gas only during the periods when the mixture passes through its flammable range.

**3-4.1.2** Mechanical ventilation may be applied in many instances to dilute an ignitable mixture well below its normal flammable range. Also, by directing the air movement, it may be practical to prevent the flammable solvents or dusts from approaching an operation where an otherwise uncontrollable static hazard would exist. To be considered reliable, the mechanical ventilation should be interlocked with the equipment to assure its proper operation.

**3-4.1.3** Where a static accumulating piece of equipment is unnecessarily located in a hazardous area, it is preferable to relocate the equipment to a safe location rather than to rely upon prevention of static accumulation.

## Chapter 4 Flammable and Combustible Liquids

**4-1 General.**

**4-1.1** Flammable liquids may form flammable vapor-air mixtures when being handled or in storage.

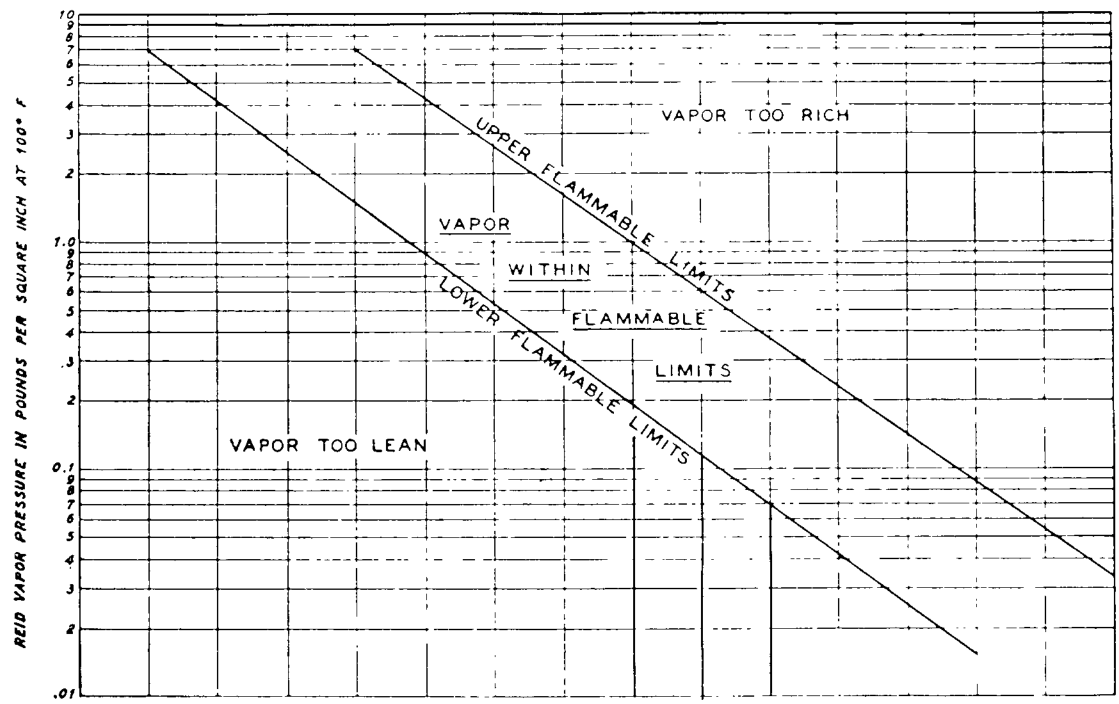
**4-1.1.1** If the liquid temperature is below its flash point, the mixture above its surface will be below the lower flammable limit, or too lean to burn. A liquid handled at or somewhat above its flash point is more likely to have a flammable vapor-air mixture at any free surface. If the temperature of the liquid is far above its flash point, the equilibrium vapor mixture at the free surface will be above the upper flammable limit, or too rich to burn. However, when loading such a liquid into a gas-free tank, the vapor space will pass through the flammable range during loading. If the vapor mixture is below or above the flammable limits, it will not ignite, even should an incendive spark occur.

**4-1.1.2** Liquids with a very low flash point, such as gasoline, have, in temperate or tropical climates, a vapor-air mixture at the liquid surface far above the upper flammable limit. Consequently, even if a spark occurs, no ignition results. However, if such liquids are handled at temperatures only slightly above their flash point, ignition becomes a possibility. In temperate climates, kerosene or other high flash point liquids are normally handled at temperatures well below their flash points. Consequently, the vapor-air mixture at the liquid surface is below the lower flammable limit and, here again, no ignition results even though a spark occurs. In the tropics, or when heated, kerosene or other high flash point liquids may reach temperatures at or above their flash points, which will produce a flammable vapor-air mixture.

**4-1.1.3** Thus, 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. Graph 4-1.1.3 shows the relationship between temperature, Reid Vapor Pressure, and flammable limits of petroleum products at sea level.

**4-1.1.4** The vapor pressure in the presence of a liquid phase depends only on temperature, and the fraction of total pressure exerted by vapor pressure determines the composition of the vapor-air mixture. Thus, at high elevations (such as in high country or in aviation) where the total pressure is low, both the flash point and the temperature corresponding to the optimum vapor-air mixture are decreased. By definition, "combustible" liquids may become "flammable" under such conditions.

**4-1.2** Static is generated when liquids move in contact with other materials. This occurs commonly in operations such as flowing them through pipes, and in mixing, pouring, pumping, filtering, or agitating. Under certain conditions, particularly with liquid hydrocarbons, static may accumulate in the liquid. If the accumulation is sufficient, a static spark may occur. If the spark occurs in the presence of a flammable vapor-air mixture, an ignition may result. Therefore, steps should be taken to prevent the simultaneous occurrence of the two conditions.




**Graph 4-1.1.3 The Relationship Between Temperature, Reid Vapor Pressure, and Flammable Limits of Petroleum Products at Sea Level.**

**Example:** With a product such as hexane [vapor pressure = 5.0 psia ( − 35 kPa)], the vapor space of a tank will be within the flammable limits for product temperatures of about −28 °F ( −33 °C) to +26 °F ( −3 °C), or when handling heptane [vapor pressure = 1.6 psia (11 kPa)] at a product temperature of 55 °F (13 °C), the vapor is within flammable limits and care to prevent static discharge should be taken.

**4-1.2.1** Filtering with some types of clay and microfilters substantially increases the ability of liquid flow to generate static charges. Tests indicate that some filters of this type have the ability to generate charges 100 to 200 times higher than achieved without such filters.

**4-1.3** To prevent an ignition it is necessary to control one or more of the following:

(a) Flammable vapor.

(b) Air (or oxygen).

(c) Source of ignition.

**4-1.4** Standard control measures are designed to prevent incendiary sparks, or the formation of ignitable vapor-air mixtures. In many cases, air, which might form an ignitable mixture with the vapor, can be eliminated or reduced in amount to render the mixture nonflammable.

**4-1.5** From the standpoint of static electricity hazard, flammable liquids may be classified according to the following characteristics:

(a) Static-generating ability.

(b) Conductivity.

(c) Flash point.

**4-1.6** A number of laboratory tests have been developed to characterize a petroleum product by its static generating ability. However, the test methods differ from each other and consequently the fuels may be rated in different orders. Then, too, there have been cases where some fuels have varied widely in their static generating ability even though they had approximately the same conductivity. Few, if any, of these tests duplicate any practical situation and for these reasons static generating ability tests, by themselves, are not reliable for predicting the static hazard. It is not practicable to eliminate completely the production of static by purification of the product.

**4-1.7** The conductivity of a liquid is a measure of its ability to hold a charge in a grounded container. (*See Section 7-8.*) The lower the conductivity, the greater the ability of the liquid to hold a charge. If the conductivity of a liquid under use conditions is greater than 50 pS/m any charges that are generated will dissipate without accumulating to a hazardous potential. (*See Appendix B for a discussion on relaxation.*)

**4-1.7.1** Experience indicates that most crude oils, residual oils (including numbers 5 and 6 fuel oils), asphalts, and water soluble liquids do not accumulate static charges.

**4-1.7.2** When a liquid is transferred into nonconductive containers (glass, plastic), the container material may hinder charge relaxation to ground. In these instances, even conductive liquids may accumulate charge. (*See Section 7-8.*)

## 4-2 Free Charges on Surface of Liquid.

**4-2.1** 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, including not only the surfaces in contact with the container walls but also the top surface adjacent to the air space, if any. It is this latter charge, often called the "surface charge," that is of most concern in many situations.

**4-2.2** In most cases the container is metal, and hence conducting. Two situations can occur, somewhat different with respect to protective measures, depending on whether the container is in contact with the earth or is insulated from it. These two situations are: (1) an ordinary storage tank resting on earth or concrete or other slightly conducting foundation; and (2) a tank truck on dry rubber tires.

**4-2.3** In the first situation of 4-2.2 the metal container is connected to ground. The charges that reach the surfaces in contact with the vessel will reunite with charges of opposite sign that have been attracted there. During all of this process the tank and its contents, considered as a unit, are electrically neutral, i.e., the total charge in the liquid and on its surface is exactly equal and opposite to the charge on the tank shell. This charge on the tank shell is "bound" there but gradually disappears as it reunites with the charge migrating through the liquid. The time required for this to occur is called relaxation time. Relaxation time depends primarily on the conductivity of the liquid. It may be from a fraction of a second to a few minutes.

**4-2.3.1** During all of this process, the tank shell is at ground potential. Externally, the container is electrically neutral. But internally, there are differences of potential between the container wall and the fluid, lasting until charges on the fluid have gradually leaked off and reunited with the unlike charges on the tank walls.

**4-2.3.2** 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. Such a spark across the liquid surface could be the cause of ignition where flammable vapor-air mixtures are present. However, a spark to the tank shell is less likely than a spark to a projection or to a conductive object lowered into the tank. No bonding or grounding of the tank or container can remove this internal surface charge.

**4-2.4** In the second situation mentioned in 4-2.2, the tank shell is highly insulated from the ground. The charge in the liquid surface attracts an equal and opposite charge to the inside of the container. This leaves a "free" charge on the outside surface of the tank that is the same sign and of the same magnitude as that in the liquid. This charge can escape from the tank to the ground in the form of a spark. In filling a tank truck through an open dome, it is this source of sparking that is suspected to have caused some fires; in this case the spark jumps from the edge of the fill opening to the fill pipe, which is at ground potential. This hazard can be controlled by grounding the container before filling starts or by bonding the fill pipe to the tank. If grounding the tank is used, the fill pipe must also be grounded. (*See Figure 2.*)

**4-2.5** The foregoing discusses the distribution of charges delivered into a container with a flowing stream. Further generation or separation may occur within the container in several ways to produce a surface charge:

(a) Flow with splashing or spraying of the incoming stream,

(b) Disturbance of water bottom by the incoming stream,

(c) Bubbling of air or gas through a liquid, or

(d) Jet or propeller blending within the tank.

**4-2.6** These charges on the surface of a liquid cannot be prevented by bonding or grounding, but 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.

**4-2.7** Use of conductivity additives will rapidly relax surface charge and prevent the build-up of a hazardous potential.

### 4-3 Storage Tanks.

**4-3.1** 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.

**4-3.2** When tanks that have spaces that may contain flammable mixtures of vapor and air are filled with static-accumulating liquids, one or more of the following protective measures [(a) through (h)] may be used, depending upon the characteristics of the liquid handled:

(a) Overshot splash filling should be prohibited except for flammable liquids that do not accumulate static, such as crude oils.

(b) Inlet fill pipe should discharge near the bottom of the tank and should be designed to reduce turbulence to a minimum. In general, the inlet stream preferably should be directed horizontally to reduce agitation of water and sediment on the tank bottom.

(c) Charge generation generally increases with flow velocity; hence, it follows that the occurrence of a static ignition is less likely with low flow velocities. Insofar as practicable, the linear velocity of the liquid in the pipe entering the tank should be kept below 1 meter per second until the pipe inlet is well submerged.

(d) Water should be kept out of the incoming stream, insofar as practicable, since the charge density, or charge per unit volume, may be increased by the presence of an immiscible liquid, such as water, in the flowing stream and by its settling out in the tank.

(e) The pumping of substantial amounts of entrained air or other gas into a tank having a vapor space should be avoided, since bubbling of a gas through the flammable liquid in the tank may generate charges and release them at the free liquid surface.

(f) If a tank contains a flammable vapor-air mixture from previous use, the tank may be made safe from explosion by ventilation (50 percent or less of the lower flammable limit) before pumping in a high flash point static-generating liquid.

(g) Care should be exercised to eliminate the chance of any ungrounded conductive floatable object finding its way into the tank since it could release all of its charge instantaneously as it approached the shell or other grounded surface.

(h) Gaging or sampling through a roof manway or other roof opening with conductive objects should be avoided until after filling has been completed and the surface turbulence has subsided. Depending upon the characteristics of the liquids, the size of the tank, and the rate of fill, a waiting period of 30 minutes or more may be required for the surface charge to dissipate to a safe level. Gaging and sampling can be carried out at any time within a metal sounding pipe that extends to the bottom of the tank, since the electrostatic field within the confines of the sounding pipe is too small to cause sparking.

**4-3.3** When flammable liquids are pumped into a floating-roof tank, the protective measures noted above are applicable until the roof becomes buoyant, after which no special precautions are necessary.

**4-3.4** Spark ignitions inside tanks cannot be controlled by external grounding connections. (*See 3-3.1 and 4-2.3.*)

**4-3.5** An external spark ignition is unlikely unless the tank is deliberately insulated from earth so that the resistance to earth substantially exceeds $10^6$ ohms.

### 4-4 Piping Systems.

**4-4.1** 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 that might produce ignition.

**4-4.2** Bonding is not needed around flexible metallic piping or metallic swing joints even though lubricated, but a bond should be provided around joints in which the only contacting surfaces are made of nonmetallic insulating material.

### 4-5 Rubber-tired Vehicles.

**4-5.1** Vehicles equipped with pneumatic rubber tires sometimes accumulate a charge of static electricity. This occurs only when the tires are dry and hence good insulators.

**4-5.1.1** Such charging can arise from two separate and unrelated processes — rolling contact of tires on the pavement, or filling fuel and cargo tanks. These are best considered separately, although, since the vehicle is separated from the ground by its tires, the electrical resistance of the tire plays an important part in both cases.

**4-5.1.2** 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.

**4-5.1.3** Drag chains (drag straps) were originally thought of as a means of bleeding the static charge back to the road as fast as generated. It is now known that a drag chain is ineffective for this purpose when the road is dry and it is, of course, not needed when the road is wet. Furthermore, drag chains are ineffective as a means of control of static during loading, as discussed below. Their use should not be required.

**4-5.2** While 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. Whether or not this can produce a hazard depends on the amount of charge and other factors, as discussed below.

**4-5.2.1** The total charge carried into a vehicle depends on the generating characteristics and the total quantity of the product delivered.

**4-5.2.2** If a 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 that limits the peak voltage that the vehicle may acquire.

**4-5.3** When loading tank trucks through open domes, experience has demonstrated that a significant static hazard can be developed. A 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. To avoid this possibility, a bond should be established between the loading piping and the cargo tank. (*See Figure 2.*) The bond connection should be made before the dome is opened, and should not be removed until the dome is closed.

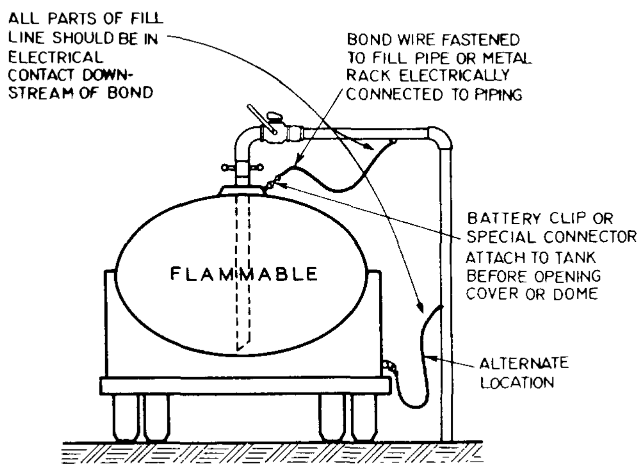



**Figure 2 Filling Tank Truck through Open Dome.**

**4-5.3.1** The fixed end of the bond wire may be connected to the fill pipe, to any part of a metal loading rack that is electrically connected to the pipe, or to ground. It is not necessary to bond around flexible metallic joints or swivel joints (unless of the insulating type) in the loading pipe. The attachment clip on the bond wire should be a battery clip or some other equivalent attachment so made that it can pull free, thus avoiding inadvertent damage that might result from driving the vehicle away without removing the bond.

**4-5.3.2** Such bonding is not required: (1) when loading vehicles with products not having static-accumulating abilities, such as asphalt and crude oil; (2) where tank vehicles are used exclusively for transporting Class II or Class III liquids loaded at racks where no Class I liquids are handled; or (3) where vehicles are loaded or unloaded through closed connections, so that there is no release of vapor at a point where a spark could occur, irrespective of whether the hose or pipe used is conducting or nonconducting. (*See Figure 3.*) A closed connection is one where contact is made before flow starts and is broken after flow is completed. (*See NFPA 321, Standard on Basic Classification of Flammable and Combustible Liquids, for information on the classification of liquids.*)

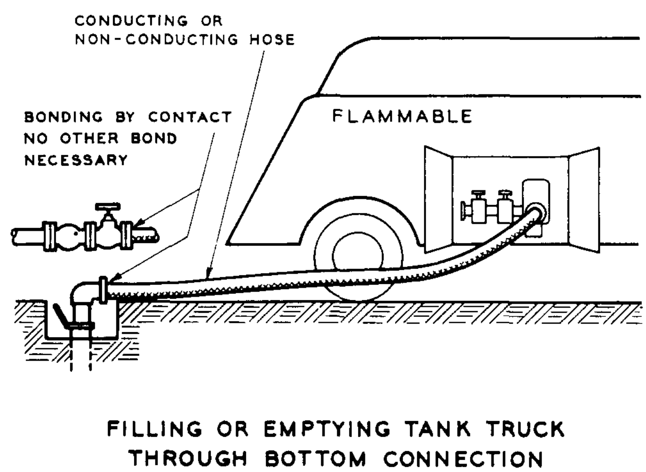



**Figure 3 Filling or Emptying Tank Truck through a Closed Connection.**

**4-5.3.3** 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 can result in an ignition when low vapor pressure products are put into a cargo tank containing a flammable vapor from previous usage, i.e., furnace oil loaded into a tank that last carried gasoline.

**4-5.3.4** During "switch loading" or when loading products that may give off vapors that are within the flammable range, excluding those enumerated in 4-5.3.2 above (*see Figure 2*), the fill pipe should reach as close as possible to the bottom of the tank being loaded, and preferably be in contact with the bottom. If the fill pipe does not reach the tank bottom, the liquid velocity in the fill pipe should be limited to approximately 3 ft (0.9 m) per second until the outlet is submerged. If the fill pipe reaches the bottom of the tank or after the outlet of the fill pipe is covered, the velocity may be increased to approximately 15-20 ft (4.5 m to 6 m) per second.

**4-5.3.5** Where bottom loading is used, low velocity or splash deflectors or other devices should be used to prevent upward spraying of the product and to minimize surface turbulence.

**4-5.3.6** All metallic parts of the fill pipe assembly should form a continuous electrically conductive path downstream from the point of bonding. For example, insertion of a nonconductive hose equipped with a metal coupling on the outlet must be avoided unless the coupling is bonded to the fill pipe. This is not required in bottom loading.

**4-5.3.7** Metal or conductive objects, such as gage tapes, sample containers, and thermometers, should not be lowered into or suspended in a compartment while the compartment is being filled or immediately after cessation of pumping. A waiting period of approximately one minute will generally permit a substantial relaxation of the electrostatic charge.

**4-5.3.8** Care should be exercised to minimize the possibility of any unbonded object entering into a tank. Prior to loading, tanks should be inspected and any unbonded object removed.

**4-5.3.9** Filters capable of removing micron-sized particles are considered prolific static generators. Therefore, a minimum of 30-seconds relaxation time normally should be provided downstream of the filter. This means that it should take at least 30 seconds for a particle of liquid to travel from the outlet of the filter element to the outlet of the fill pipe discharge into the tank truck compartment. Relaxation time may be obtained by enlarging or lengthening the pipeline, by installing a retention chamber, or by reducing the flow rate.

**4-5.3.10** Where conductivity additives are used, reduced flow restrictions or relaxation may not be necessary, but bonding and grounding precautions need to be followed.

**4-5.4** No external bond wire or bond wire integral with a hose is needed for the unloading of flammable liquids into underground tanks through a closed connection. (*See Figure 3.*)

### 4-6 Aircraft.

### 4-6.1 Fueling and Refueling of Aircraft on the Ground.

**4-6.1.1** When fueling aircraft, the aircraft should first be bonded to the tank truck, drum, fueling cabinet, hydrant, or pit, thus providing a low-resistance path to permit reuniting of separated charges; that is, so that charges delivered into the fuel tanks of the aircraft may reunite with charges left on the tank truck or other type of fueler.

**4-6.1.2** When fueling is by over-the-wing delivery, the fuel nozzle should be connected to a metal part of the aircraft which is metallically connected to the fuel tank at a point near the tank fill opening by means of a short bond wire and clip or plug. This connection should be made before the fill cap is removed and the nozzle is placed in the fill opening. It should not be detached until filling has been completed and the fill cap has been replaced.

**4-6.1.3** When fueling is by underwing delivery, the fueling is through a closed system. This closed system provides metal-to-metal contact and thus inherent bonding at the point of connection so that the bond connection mentioned in 4-6.1.2 is not required.

**4-6.1.4** If nonmetallic conductive hose is used, it should not be regarded as a substitute for bonding.

**4-6.1.5** When defueling aircraft, the static-protective measu:. s should be the same as those taken during fueling operations.

**4-6.1.6** Some regulations require, in addition to the bonding required in this section, that the aircraft and fueling system be connected by wires to ground. However, in many locations grounds are not available and evidence does not indicate that grounding is necessary for protection against static ignition. (*See NFPA 407, Aircraft Fuel Servicing.*)

### 4-6.2 Airborne Aircraft.

**4-6.2.1** Bonding of aircraft parts to provide equalization of the potential between various metallic structures of the aircraft is desirable. While such bonding is common, portions of aircraft may be insulated, either because of imperfect bonding or because they are incapable of being electrically bonded (i.e., antenna lead-ins might be a source of static spark inside the aircraft structure when the antenna lead-in is connected to its receiver through a capacitor). Unbonded portions constitute a static fire hazard where flammable vapors are present and an explosion hazard where such flammable vapors exist within confined areas or structures of an aircraft.

**4-6.2.2** High humidity conditions do not aid in the dissipation of static electrical charges on airborne aircraft as is occasioned on objects resting on the ground simply because of the absence of any continuous solid surface between the aircraft and the ground on which a moist film can be deposited. In fact, when humidity reaches the saturation point, an increase in precipitation static results. Small traces of water vapor in a film on an insulator (as might be imparted by condensation) do, however, render some insulators conducting.

**4-6.2.3** Static dissipators can only attempt to approach the theoretical ideal, which would be to discharge instantly the electrostatic charges generated on the aircraft so that there would be no difference of potential with the surrounding atmosphere. This is true since ionization cannot start until the impressed potential gradients of the aircraft attain their ionizing threshold intensities. Static dissipators will safely lower dangerous potentials from aircraft if they are of proper design and installed in adequate number at electrically strategic locations.

**4-6.2.4** It should be stated explicitly that the development of static charges on airborne aircraft offers a fire or explosion hazard only where flammable vapor-air mixtures exist and every effort should be made to eliminate all constructions and procedures that could produce accumulations of such flammable vapor-air mixtures.

### 4-7 Tank Cars, Tankers, and Barges.

### 4-7.1 Tank Cars.

**4-7.1.1** When loading or unloading tank cars through open domes, the downspout should be of sufficient length to reach the tank bottom. (*See 4-5.3.2 for Exception.*)

**4-7.1.2** The resistance of tank car to ground through the rails and the resistance of piping, flexible metallic joints, or metallic swivel joints are considered to be adequately low for protection against static electricity.

**4-7.1.3** When loading or unloading tank cars through closed connections, no protective measures need be taken. (*See 4-5.3.2.*)

### 4-7.2 Tankers and Barges.

**4-7.2.1** The loading and unloading of steel tank ships and barges does not require any special measures to protect against external static sparks. Bonding cables between the vessel and shore are not required. The hull of the vessel is inherently grounded by virtue of its contact with the water. Consequently, the accumulation of static charges on the hull is prevented.

**4-7.2.2** Loading or discharging liquids from vessels is through closed systems. These vessels are, in general, in adequate contact with the earth so that external static sparks are prevented. 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. (*See Sections 4-3 and 4-4.*)

**4-7.2.3** The discussion given in Section 4-3 regarding pumping of flammable liquids into storage tanks having a vapor space also applies to the flow of such liquids into ships' tanks.

## 4-8 Container Filling.

**4-8.1** Filling portable containers is analogous to filling tank vehicles except that the smaller size and lower flow rates may permit less rigorous static control measures. (*See Section 4-5.*)

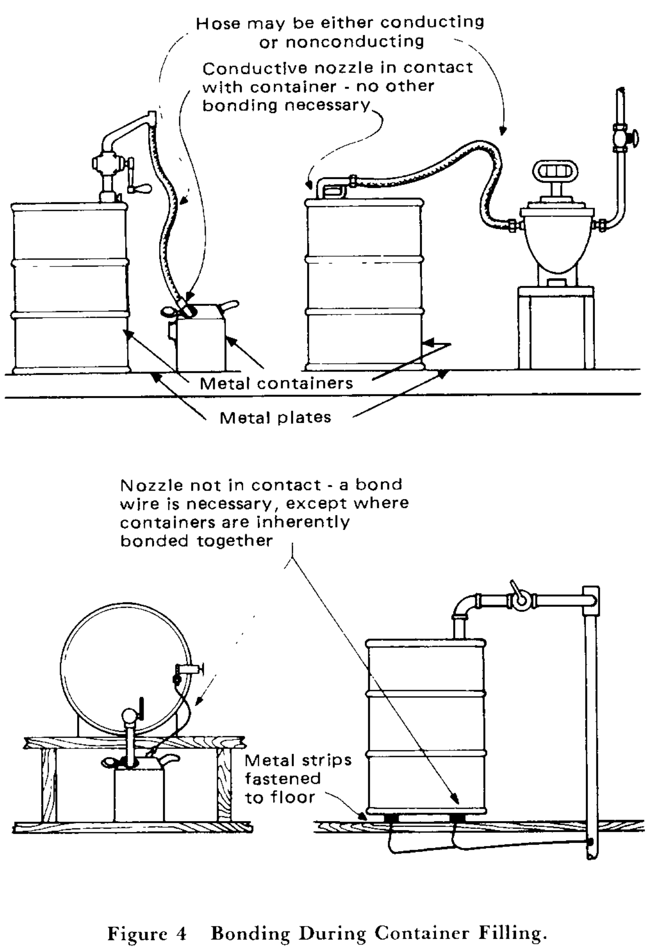



**Figure 4 Bonding During Container Filling.**

**4-8.2** In filling metal cans and drums, a fill spout, nozzle, or fill pipe, if conductive, should be kept continuously in contact with the edge of the fill opening. Conductive funnels, strainers, or other devices should likewise be kept in contact with both the fill nozzle and the container to avoid the possibility of a spark at the fill opening. Under these circumstances the additional precaution of providing a bond wire between the container and the fill connection is not warranted.

**4-8.3** The need for extending a downspout to the bottom of the container has not been demonstrated by experience in filling containers up to and including 55-gal (208-L) drums.

**4-8.4** When contact cannot be maintained between the fill pipe and the container, and the two are not inherently bonded, a bond wire should be used between them. Figure 4 illustrates various protective measures used in container filling.

**4-8.5** Containers of glass or other nonconducting materials of 5 gal (19 L) or less capacity are usually filled without special precaution. For larger containers, see Section 7-8.

**4-8.6** Bonding is not required where a container is filled through a closed system.

**4-8.7** Microfilters, if used, should be as far upstream of the nozzle as practicable. Transfer lines downstream of the filters should be conductive.

# Chapter 5 Dusts and Fibers

**5-1 General.** This chapter contains a discussion of some of the static electricity problems associated with the handling and processing of dusts and fibers.

## 5-2 Parameters Affecting Charge Generation.

**5-2.1** A transfer of an electric charge occurs when two materials in contact are separated. Dust dispersed from a surface may develop a considerable charge. The ultimate charge depends on the inherent properties of the substance, size of particle, amount of surface contact, surface conductivity, gaseous breakdown, external field, and leakage resistance in a system. Electrification develops during the first phase of separation. Subsequent impact of airborne particles on obstructions may affect their charge slightly, but if the impact surface becomes coated with the dust, this effect is slight.

**5-2.2** Charge generation seldom occurs if both materials are good electrical conductors, but it is likely to occur with a conductor and a nonconductor or two nonconductors. When like materials are separated, as in dispersing quartz dust from a quartz surface, positive and negative charges are developed in the dispersed dust in about equal amounts to give a net zero charge. With materials differing in composition, a charge of one polarity may predominate in the dust. Each of the materials becomes equally charged but with opposite polarity. With a metallic and an insulating material, the former usually assumes a positive and the latter a negative polarity.

5-2.3 Electrostatic charge generation in moving dust normally cannot be prevented. High humidity or grounding of the surface from which dust is dispersed will not eliminate the charge generation. The method of dispersion of the dust, the amount of energy expended in dispersal, the degree of turbulence, and the composition of the atmosphere usually do not affect the magnitude or distribution of the charges.

5-2.4 The voltage developed by dispersion of dust from a surface is proportional to the quantity of dust dispersed, and the maximum voltage developed depends on the leakage resistance in the system and corona or spark discharge.

**5-3 Ignition of Dust by Static Discharge.**

5-3.1 Dust clouds and layers of many combustible materials (with or without a volatile constituent) have been ignited experimentally by static discharge. In some instances, the charge was generated by movement of dust, in others by a static generator (Wimshurst machine), or by electronic equipment.

5-3.1.1 With dust clouds, it has been shown that a minimum dust concentration exists below which ignition cannot take place regardless of the energy of the spark. At the minimum dust concentration 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.

5-3.1.2 The circuit resistance required for optimum igniting power varies with the capacitance, the voltage, and the type of dust; it often ranges from 10,000 to 100,000 ohms. In this connection, it should be noted that metallic dust layers are usually poor electrical conductors unless compressed.

5-3.2 The minimum electrical energy required to ignite a dust cloud is typically in the range of 10 to 80 millijoules and rapidly diminishes with decreasing particle size. Thus, many dusts can ignite with less energy than might be expended by a static discharge from machinery or from a human body. Layers of combustible dust can be ignited by static discharge, but there is little correlation in the minimum energy required for ignition of dust layers and clouds. Layers of some metallic dusts such as aluminum, magnesium, titanium, and zirconium require less energy for ignition than carbonaceous materials.

5-3.3 Dust clouds may be readily ignited when present as a "hybrid mixture" with a flammable gas or vapor. (*See 1-7.4.*) Special precautions should be adopted when any nonconductive components (drum liners, etc.) are present in such cases. (*See Section 7-9.*)

**5-4 Cotton Gins.**

5-4.1 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.

5-4.2 The generation of static on the cotton can be minimized by the introduction of moisture or an antistatic agent.

5-4.3 The bonding and grounding of cotton gin equipment will not prevent or remove the static accumulation from the cotton being processed.

**5-5 Control Measures.** The principal methods of controlling static electricity associated with dusts are:

(a) Use only conductive equipment and keep all components grounded.

(b) Avoid projections and probes that could lead to discharges between a charged dust pile and a probe.

(c) Ionize the air to provide a means of discharging the dust.

(d) Avoid a flammable condition by inerting the container.

## Chapter 6 Gases

**6-1 General.**

6-1.1 Gases not contaminated with solid or liquid particles have been found to generate little, if any, electrification in their flow.

6-1.2 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 object will charge the latter unless the object is grounded or bonded to the discharge pipe.

6-1.3 When any gas is in a closed system of piping and equipment, the system need not be electrically conductive or electrically bonded, except that electrically isolated conductive sections should not be used.

**6-2 Air Under Pressure.** Compressed air containing particles of condensed water vapor often manifests strong electrification when escaping.

**6-3 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. High pressure carbon dioxide should not be discharged into flammable atmospheres because it presents a high risk of ignition.

**6-4 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. In the pure state, no static charges are generated by the flow of hydrogen. However, as gaseous hydrogen is commercially handled in industry, such as flowing through pipelines, discharging through valves at filling racks into pressure containers, or flowing out of containers through nozzles, the hydrogen may be found to contain particles of oxide carried off from the inside of pipes or containers. In this contaminated state, hydrogen gas will generate static, and may be ignited.

### 6-5 LP-Gas.

**6-5.1** The liquefied petroleum gases (LP-Gases) behave in a manner similar to that discussed in 6-1.1 in the gas phase and 6-1.2 in the mixed phase.

**6-5.2** Bonding is not required where vehicles are loaded or unloaded through closed connections, so that there is no release of vapor at a point where a spark should occur, irrespective of whether the hose or pipe used is conducting or nonconducting. A closed connection is one where contact is made before flow starts and is broken after flow has ended.

## Chapter 7 Industrial and Commercial Processes

### 7-1 Belts.

**7-1.1 General.** Rubber or leather flat belts or vee belts used for the transmission of power or belts used for the transportation of solid material may generate static and warrant corrective measures if there is a possibility that ignitable atmospheres, dusts, or fibers may be present.

#### 7-1.2 Flat Belts.

**7-1.2.1** Rubber or leather flat belts are usually dry and good insulators because friction causes them to operate at temperatures higher than the surrounding atmosphere. Static generation occurs where the belt leaves the pulley and may occur with either conducting or nonconducting pulleys.

**7-1.2.2** Charge accumulation may be prevented by employing belts of the antistatic type that are made of conductive materials. It may also be prevented by applying a special type of conductive dressing to the belt. To be effective, these dressings must be renewed frequently.

**7-1.2.3** A grounded static comb 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 charge. (*See Figure 6D.*)

**7-1.3 Vee Belts.** Vee belts are not as susceptible to hazardous accumulations of electric charge as flat belts. Under certain conditions of temperature and humidity, however, a vee belt drive may generate a significant quantity of static electricity. Where flammable vapors are present it is safe practice to employ vee belts of the conducting type. Conducting type vee belts should be kept free of accumulations of nonconducting material. In areas where flammable vapors are likely to be present, direct drives are preferable to vee belts, although it is generally considered that the risk from the standpoint of static is small.

#### 7-1.4 Conveyor Belts.

**7-1.4.1** Belts used for the transportation of solid material usually move at slow velocity and normally would not be 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 may be significant.

**7-1.4.2** Materials spilled from the end of a conveyor belt into a hopper or chute may carry a static charge. If such charges cause difficulty, the belt support and terminal pulleys should be electrically bonded to the hopper. Static neutralizers installed close to the end of the conveyor where the materials spill off may also be helpful.

#### 7-1.5 Pulleys and Shafting.

**7-1.5.1** Metal pulleys will pick up a charge equal and opposite to that carried by a belt that runs over them, and will communicate this charge to the supporting shaft and thence through bearings to the equipment and the earth. In special cases involving nonconducting components that isolate metal parts, it may be necessary to bond or ground the isolated metal portions of the equipment.

**7-1.5.2** It has been found that lubricated bearings are usually sufficiently conductive to allow a static charge to leak off the shafts. However, the conductance across bearings operating at very high RPM may not be sufficient to prevent accumulation of static charge when the charge generation rate is high. For this reason, shafts rotating at very high RPM should be bonded or grounded through a sliding contact to the housing.

### 7-2 Coating, Spreading, and Impregnating.

**7-2.1** Coating, spreading, and impregnating operations are quite similar to each other 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, and the method used is determined by the viscosity and temperature of the coating of the impregnating solution, the speed of the machine, the thickness of the coating desired, or the depth of the impregnation. Figure 5 shows a typical cloth coating machine.

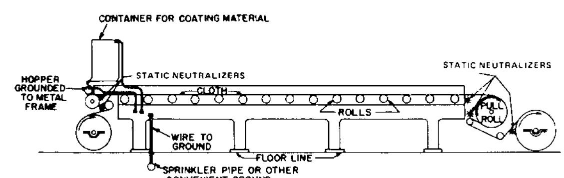



**Figure 5 Grounding of Cloth Coating Machine (Metal Frame) Showing Location of Static Neutralizers.**

**7-2.2** Charge accumulations on the coated material depend to a considerable degree on the materials of which the rollers are made. In some cases, charge accumulations can be greatly reduced by the selection of materials used for the roller. For example, conductive rolls in place of rolls covered with nonconductive materials may be helpful.

**7-2.3** The operator should wear conductive footwear. Working platforms around coating machines should be conductive and grounded, and kept clean so that the operator does not become insulated from ground.

7-2.4 When flammable liquids are employed in the process, definite precautions must be taken against possible ignition of flammable vapor-air mixtures. Static neutralizers (*see Figure 6*) should be installed where the rolls of materials are unwound or where the webs pass over the roller or under spreader knives or doctor blades. See Figure 6 for positions of maximum effectiveness. All conductive parts of a machine should be bonded together, and unless the machine is inherently grounded, the frame of the machine should be permanently grounded.

7-2.5 Where flammable liquids are used, adequate forced ventilation should be provided for the area and the equipment to prevent flammable vapor accumulations. (*See NFPA 34, Dipping and Coating Processes.*)

7-2.6 If humidification is not injurious to the process, maintenance of relative humidity of 50 percent or greater will be most helpful in the mitigation of static accumulations. Local humidification and the installation of steam jets at the feed end of the machine and at other points of static generation have been found in some cases to be a practical means of static control. (*See Section 7-6.1.*)

7-2.7 Solvent containers such as hoppers should be enclosed and preferably filled through a closed piping system.

**7-3 Printing and Lithographing.**

**7-3.1 General.** There are electrostatic problems associated with the printing and lithographing industry, and they may be addressed as shown in 7-3.2 through 7-3.4.9.

**7-3.2 Paper.**

**7-3.2.1** The character of the paper surface has a great deal to do with the amount of static generated. Paper will acquire static charges in the following processes: folding machines, die cutting, eyeletting, deckling, pebbling and roughing, laminating, perforating, stapling, and tipping.

**7-3.2.2** The hygroscopic quality of the paper is also determined to some extent by the character of the surface of the paper, which likewise has a distinct bearing on the generation of static by the paper. The more water content in the paper the less will be the amount of static generated. The difficulties in processing cellulose acetate sheets that are moistureproof is an excellent example in support of this statement.

**7-3.2.3** If all paper used in the paper industry were in equilibrium with the air at a relative humidity of 70 percent or more, there would probably be little need for other means of static control. However, in the attempt to reduce the generation of static by increasing the moisture content, other production problems are sometimes introduced because paper will change in dimension and flexibility with changes in moisture, and registration defects may result. The ink drying rates may also be affected.

**7-3.3 Inks.**

**7-3.3.1** The inks used in letter presses and lithograph presses contain only slightly volatile solvents having flash points in the 300°F (140°C) to 400°F (204°C) range and present little fire or explosion hazard. High speed printing

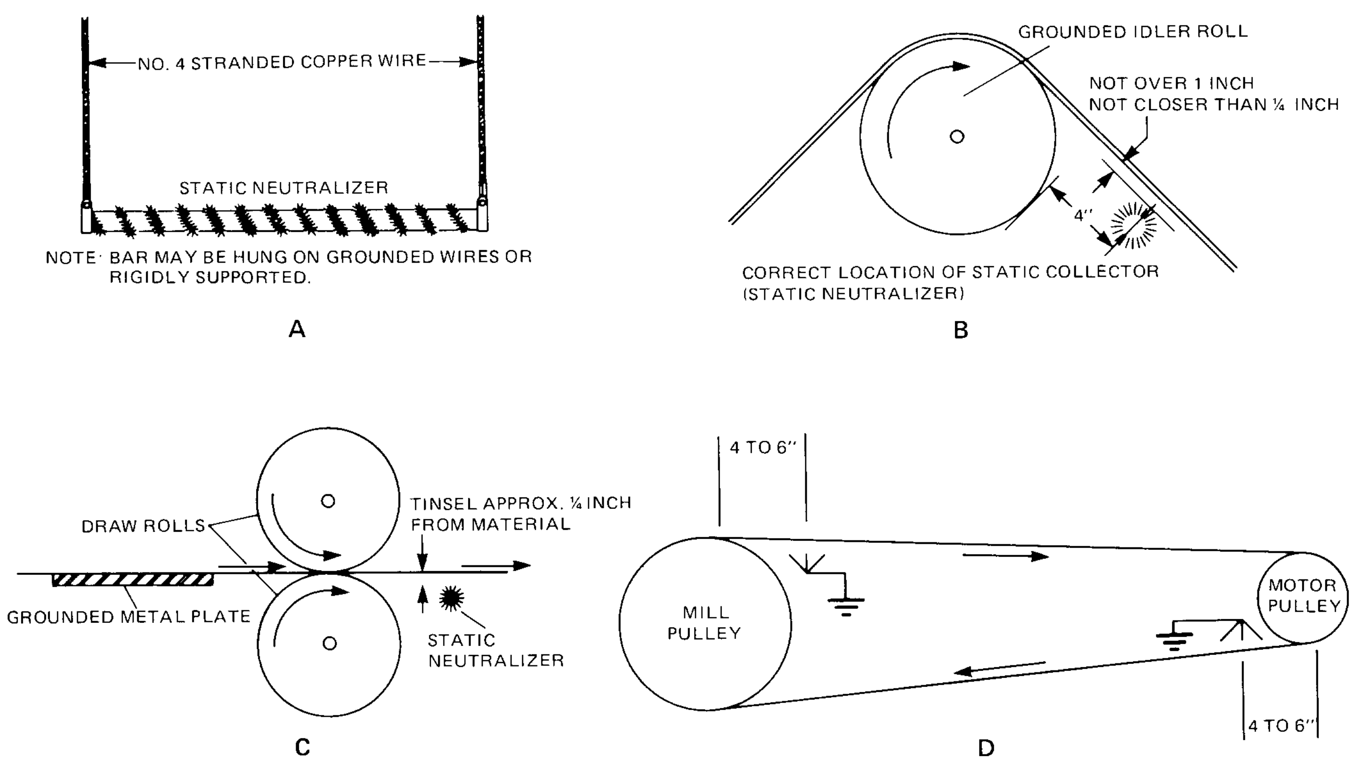



Figure 6 Static Removal from Nonconducting Materials.

or rotogravure presses and flexograph presses require the use of low flash point solvents having flash points in the range of 20°F (−4°C) to 120°F (49°C). Fires can occur due to the use of the low flash point solvents whose vapors can be ignited by static sparks or other ignition sources.

### 7-3.4 Presses.

**7-3.4.1** A great deal of 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 between the impression and the final delivery roll or stack. Printing on plastics, vinyls, and other synthetic materials causes more static problems than printing on paper.

**7-3.4.2** A 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 neutralizers are commonly used in close proximity to the paper, as described in 3-3.4. However, the reduction of static at any one point in the operation does not prevent the generation of static in later steps of the process; static neutralizers may be necessary at a number of locations. (*See Figure 7.*) Also, static bars are frequently attached to the fly to remove static from the delivered sheets. For fast running presses, inductive neutralizers, such as tinsel wrapped around a bar, or grounded needle points spaced 0.5 to 1 in. (12.70 to 25.40 mm) apart, have been found to be effective.

As with all neutralizers, positioning is important, and effectiveness of individual installations should be confirmed by field measurement of residual change. (*See 3-3.4.2.4.*) The neutralizer should be located as far as possible from grounded metallic press parts or areas where the web is supported by rollers, and must not interfere with the pathway of the web.


**Figure 7 Static Removal from Printing Rolls.**

**7-3.4.3** Tinsel or needle points remain functional only as long as they are clean and sharp. Accumulation of soil and corrosion products must be controlled by an effective maintenance program.

**7-3.4.4** Humidification is one of the most successful methods of controlling static electricity. (*See 3-3.2.*) The amount of moisture required and the method of introducing it in the air differ somewhat depending on the paper being run and local pressroom conditions. Usually a range from 45 percent to 60 percent relative humidity is most practical. In plants with ventilating systems humidification is comparatively simple and, in others, moisture is introduced most easily by means of escaping steam.

**7-3.4.5** In addition to the above methods of controlling static, a very common device used on presses is the open gas flame. This, of course, can only be used in presses using inks of low volatility. The open flame is placed across the press at the delivery end so as to allow the paper to pass through the flame quickly or very close to the heater. In every case where a gas flame is used for static neutralization, the burner should be interlocked with the press so that the flame will be out when the press is stopped. It is necessary to make sure that the pilot of the burner cannot touch the edge of the paper.

**7-3.4.6** The electric neutralizer is used frequently for the elimination of static on all presses, but more particularly on rotary-type presses. (*See 3-3.4.*) Ink spray from the ends of the rolls tends to accumulate on the ends of the neutralizers and it is important that they be kept reasonably clean at all times because heavy ink deposits have caused electrical breakdown of the neutralizers in a few cases.

**7-3.4.7** Higher operating speeds have resulted in the development of the enclosed ink fountain, which makes for 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 vapors below the lower flammable limits.

**7-3.4.8** From the fire standpoint, presses of slow speeds do not present the static problem exhibited in high-speed presses. Inks used on flatbed presses are nearly always of low volatility. However, the static electricity problem from the production standpoint still exists. This type of press, using individual sheet paper, is used for multicolor work when it is frequently necessary to run work through two or more presses. The problem of exact register as well as a satisfactory delivery of the individual sheets from the fly is affected by static buildup in the printing. Even releasing the sheet from the tympan is sometimes difficult. One of the most satisfactory treatments for adhesions to the tympan is the use of glycerine and acetic acid to dampen it.

**7-3.4.9** With dry paper, in a dry atmosphere, a rotogravure press can become a static generator. A rubber roll is pressed with as much as 4 tons (907 kg) of pressure against a copper etched roll, which revolves in a volatile ink, and the paper passes between the two rolls. In a multicolored press there is a similar arrangement for each color. 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 press room air humidification are also effective in reducing static effects on rotogravure presses. For more complete control, however, a static neutralizer covering the full width of the web at the delivery side of each impression roller is usually necessary.

**7-4 Mixing and Blending Operations.**

**7-4.1** In the mixing and blending of flammable liquids, or of particulates in a flammable liquid, one of the more common methods employed to drain off static is to bond and ground all metal parts and all moving parts of the equipment. Consequently, metal and other conductive material should be used as far as possible in design of components that are contacted by the material being processed, although this may not prevent the accumulation of static charge on the mixed material.

**7-4.2** Bonding and grounding as recommended will not remove the free charge on the surface of the liquid. (*See Section 4-2.*)

**7-4.3** Jet mixing and propeller mixing in tanks may generate charges. Care should be taken to avoid agitating a possible layer of water at the bottom of flammable liquid tanks. The jet or propeller stream should be directed so as not to break the surface. Jet mixing nozzles should not be used for filling tanks when the nozzles are above the liquid surface. Where flammable mixtures may be encountered above the liquid surface, inert gas blanketing may be employed. (*See NFPA 69, Standard on Explosion Prevention Systems.*)

**7-4.4** Floating-roof tanks eliminate the vapor space and, therefore, are especially desirable for hazardous blending service.

**7-4.5** Good housekeeping is of prime importance in areas where dust or powders from the operations are produced. The building and equipment should be designed to eliminate shelves and ledges and similar places where such materials can accumulate.

**7-4.6** Care should be taken to prevent tramp metal, tools, or loose hardware from getting into the ducts and containers.

**7-4.7** In the manufacture of lacquers and coating materials, 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 incorporating conductivity additives in nonconductive solvents.

**7-5 Film Casting and Extrusion.** In the manufacture of thin films the generation of static charge may be appreciable especially when nonconducting coating materials are employed. When conductive coating materials are used, the hazard increases as the solvent is evaporated from the product unless the finished product is also conductive. The static charge on the product can be reduced by ionizing the air in the immediate vicinity. Ionization can be achieved by the use of static combs, tinsel brass, or by the use of radioactive materials.

**7-6 Steam Jets.**

**7-6.1** Surfaces on which steam condenses may accumulate static unless the surfaces are bonded to the discharging pipe or both units are grounded. A resistance between connecting parts of $10^6$ ohms or less should be adequate. If flammable vapor-air mixtures are likely to be present, steam jets should be avoided. Also, when a steam eductor is used to ventilate a tank containing a flammable vapor, the eductor should be used so that it will pull the vapor out of the tank (not blow steam into the tank), and it should be electrically bonded to the tank.

**7-6.2** When steam cleaning constitutes a hazard, all pipes or nozzles through which steam is discharged should be bonded to the equipment being steamed or the two objects should be connected to ground.

**7-7 Spray Application of Flammable and Combustible Materials.** (*See NFPA 33, Spray Application Using Flammable and Combustible Materials.*)

**7-7.1** Ignition of flammable mixtures in paint spray facilities is often the result of the discharge of static electrical accumulations.

**7-7.2** With the airless spray system, static can accumulate upon the object being sprayed and upon the spray gun. A particularly hazardous condition exists when the equipment is being flushed through the gun (as for color change) and the fluid stream from the gun is directed into an electrically isolated pail or drum. Where flammable liquids are involved, any conductive object being sprayed and any container to collect the fluid discharge of the gun must be bonded to the spray equipment or both the pieces must be grounded so that the spray-generated charge can be dissipated without sparking.

**7-7.3** Electrostatic spray equipment for applicaton of fluids or of powders is deliberately operated at high (30kV-150kV) voltage to enhance deposition of coatings on the workpiece.

**7-7.3.1** Some types of this equipment (commonly referred to as "stiff" systems) are capable of discharging incendive sparks that may ignite flammable mixtures or produce electroshock injuries. Attempts to prevent such sparking by adjustment of distance between atomizer and workpiece are unreliable because sparking distance through vapor or aerosol burdened air is not predictable. When equipment capable of such sparking is used, it should be surrounded with protective fencing and interlocks to protect personnel and, when used with flammable or combustible coating materials, should be protected by highly engineered fire suppression systems.

**7-7.3.2** A class of equipment does exist that, while operating in the same voltage range, is not capable of producing discharges with enough energy to start fires or to cause electroshock injuries. These devices, referred to as nonincendive, may be operated without the fencing and extraordinary fire protection called for by "stiff" systems, as they will not spark at any distance.

**7-7.3.3** During operation of any electrostatic equipment, however, electrically conductive isolated objects within the process area are influenced by the process and may become charged to voltages that result in spark discharges capable of igniting flammable or combustible substances. Objects commonly involved in such incidents include workpieces on conveyor racks that have fouled contact points; solvent containers or tools placed upon nonconducting paint residues, cardboard, or wooden rests; spray-booth components such as loose floor grates; and human beings insulated from ground by rubber footwear, paint residue accumulations on floors, and gloves.

**7-7.4** Even in spray painting environments where there is no electrostatic equipment in operation, but where sticky, electrically nonconductive paint residues have accumulated on the floor, a significant hazard is associated with static electrification of human bodies that results from walking across such a floor. As few as two or three steps may produce sufficient voltage on the body of a worker to create an incendive spark when he approaches a grounded object. If this spark occurs in a flammable vapor such as is found surrounding a solvent container or a freshly painted object, a fire results.

**7-7.5 Prevention.**

**7-7.5.1** To prevent ignition by sparks from accumulation of static electricity on such random objects, all electrically conductive objects (including human bodies) within the process area must be electrically bonded or grounded. High voltage power supplies for electrostatic systems should be provided with control interlocks that allow the equipment to be energized only during actual spraying operations.

**7-7.5.2** To minimize the hazards from the electrostatic spray equipment, only listed equipment should be used and it should be installed and maintained in accordance with the manufacturer's recommendations.

**7-8 Nonconductive Containers.**

**7-8.1 Liquid Handling.** The handling of flammable materials in plastic containers of various sizes ranging from 5 to 55 gal (19 to 208 L) capacity is potentially hazardous. While filling the container, charges generated by splashing, turbulence, or filtering can accumulate on the surface of the liquid or on conducting components insulated from ground. Charges may also be generated by rubbing on the external surface of the container while shipping or handling. These charging mechanisms may result in an incendive discharge. Recommended safeguards are to ground all metal parts on or near the container and provide for charge relaxation by bottom filling with a grounded lance.

**7-8.1.1 Portable Containers.** The handling of flammable materials in portable containers is potentially hazardous, even if the liquid is conductive. Incendive discharges may occur either from charged liquid in the container or from the container itself, if the container is charged by rubbing or another process. If a nonconductive container must be used, a discharging electrode should be present in the liquid throughout filling. This may consist of a grounded dip pipe or a grounded wire. All conductive elements such as funnels must be grounded during filling. The filling rate should be minimized, particularly if an upstream filter is present, and the discharging electrode or dip pipe retained in the liquid for at least 30 seconds after filling any low conductivity liquid (less than 50 pS/m). An additional hazard may arise if nonconductive containers are used in areas containing ambient flammable mixtures, owing to the possibility of the container surface becoming charged. Also, the ignition risk posed by ungrounded personnel should be considered. Special advice should be obtained before adopting a procedure involving low conductivity liquids and nonconductive containers exceeding 1 gal capacity.

**7-8.1.2 Fixed Containers.** The use of fixed, nonconductive containers exceeding 55 gal capacity is not recommended for flammable liquid service unless proper design and procedures can be demonstrated. Specialist advice should be obtained particularly if low conductivity liquids are involved. The design should, at a minimum, involve grounding of all conductive components and the use of a grounded dip pipe. Additional methods to aid charge relaxation, such as the use of submerged grounded plates or grids, involve consideration of the container geometry with respect to external grounded bodies, and their proper size and placement cannot be generalized.

**7-8.2 Powder (Dust) Handling.**

**7-8.2.1 Paper Sacks and Fiber Drums.** These containers may be considered conductive. Paper sacks are grounded when in contact with grounded personnel or when resting on a grounded surface, such as the loading port of a process vessel. Fiber drums may be grounded by means of a grounding cable and clip. (*For nonconductive liners, see Section 7-9.*)

**7-8.2.2 Plastic Bags and Drums.** These containers readily become charged and can give rise to discharges either from their surfaces or by inductively charging ungrounded personnel. They should not be used to transfer powder to flammable liquids or where hybrid mixture may form, or used with sensitive powders of low ignition energy. Personnel should be properly grounded.

**7-8.2.3 Large Containers and Tote Bins.** In addition to the provisions of 7-8.2.2, a grounded rod should be placed in the container during filling to prevent "capacitor like" charge accumulation on the container walls.

**7-9 Container Linings.**

**7-9.1** Linings may be conductive, such as conductive plastic or aluminum foil, or nonconductive. The hazard due to conductive liners is addressed by grounding. Nonconductive liners have a wide range of conductivity and would constitute a hazard if the liner impedes the relaxation of any charge. Both antistatic and conductive linings are commercially available.

**7-9.2 Liquids.**

**7-9.2.1** Containers for liquids may be deliberately lined or may become lined by deposition of material, such as when a liquid solidifies at the wall or forms gums or resins. If the lining impedes charge relaxation, more charge may accumulate than in the case of a conductive container. Thin linings of paint or epoxy or phenolic resins may usually be neglected. If the surface resistivity of the lining exceeds $10^{11}$ ohms, the use of a grounded dip pipe of conductive material should be considered. Dip pipes should always be used for high resistivity linings such as polyethylene (for example, poly-steel drums). If a microfilter is used in low conductivity liquid service, additional precautions are necessary for high resistivity linings. If adequate relaxation time cannot be provided between the filter and the container, inerting should be considered.

**7-9.3 Powders (Dusts).**

**7-9.3.1 Conductive Containers.** Nonconductive liners such as polyethylene should not be used in cases where a hybrid mixture may be present, or for sensitive dusts with low ignition energy. In particular, the liner should not be allowed to leave the container or shaken out in areas where flammable vapor may be present, such as at the loading port of a process vessel. Fixed liners such as paint or epoxy resin are not believed to pose any additional ignition hazards. Particular attention should in all cases be made to grounding of the container. In the case of a fiber drum, both upper and lower chimes should be grounded if a polyethylene liner is present. Especially in the case of paper sacks, personnel should be grounded, since direct handling of an otherwise ungrounded container relies on grounding through the person involved.

**7-9.3.2 Nonconductive Containers.** If a conductive liner such as conductive plastic is used, attention should be made to ensure that the liner is properly grounded. Otherwise, any charge accumulated on the liner could discharge as an energetic spark.

## Chapter 8 Detection and Measurement of Static Accumulation

**8-1 General.**

**8-1.1** To evaluate the degree of hazard of static charge buildup it is necessary to identify its location and to determine its magnitude. Of the many types of measuring devices that are available, most fall into one of the following categories: electrometer, electrostatic voltmeter, or field mill. Depending on how it is used, an electrometer can measure the voltage, accumulated charge, or current. An electrostatic voltmeter measures the voltage. A field mill measures the field strength (volts per unit distance) in space without direct contact to the charges producing the field. In addition there are various hand-held, noncontact devices that can give a qualitative indication of static charge on objects to which they are pointed.

NOTE: Extreme care should be used so that neither instruments nor testing techniques cause ignition of flammable atmospheres. For example, apparatus can often be designed to be intrinsically safe, or can be enclosed in a purged or explosion-proof housing with special protective circuitry to prevent hazardous energy levels appearing at the exposed sensing elements

**8-1.2** To make meaningful determinations of hazard level, it is important that the appropriate type of instrument be used and that its reading be properly interpreted. A noncontacting instrument responds to the magnitude (and, in some cases, the polarity) of the electric field strength at its sensing aperture even though it may be calibrated in terms of volts or charge. The field strength at the meter may be quite different from the field adjacent to the static charges, in which case the meter reading does not accurately indicate the degree of hazard. The measuring technique for charged conductors differs from that for nonconductors. The voltage on a conductor can be measured by contact. Measurement of the voltage of nonconductors is seldom appropriate or feasible since the voltage varies from point to point and is changed by the introduction of a measuring device.

**8-1.3** Charged nonconductors can take many different forms: paper, film, webs, powders, liquids, process rolls, extrusions, etc. Determination of charge level on powders or liquids is best made with an electrometer measurement of charging current or accumulated charge that can be related to charge per unit mass or charge per unit volume. Measurement of charge buildup on surfaces such as paper, film, webs, process rolls, etc. is most readily made in terms of electric field strength (volts per unit distance) over the surface from which the charge per unit surface area can be inferred. Because charge densities on nonconducting surfaces are typically nonuniform, the area measured by the instrument can have a significant effect on its readings.

**8-1.4** The relationship between the charge level on a nonconductor or the electric field strength and the available spark energy is not defined as is the case for conductors. Empirical relationships have been developed for some applications such as the handling of flammable liquids and the processing of plastic film in a flammable environment.

**8-2 Electrometers.**

**8-2.1** Electrometers are frequently used for laboratory and field investigations of static electricity. These instruments employ special input stages that provide the high input resistance (typically $10^{14}$ ohms or more) needed to avoid dissipation of the measured charges. Equally important, they have very low bias current, that is, a self-generated current at the input (typically less than $10^{14}$ ampere). Although the maximum full-scale range of the electrometer is usually only 10 or possibly 100 volts, static potentials 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.

**8-2.2** 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 noncontact measurements with a probe that exposes the input terminal of the electrometer to the electrostatic field of a charged object. In effect the probe is a capacitive divider.

**8-2.3** The capacitive probe/electrometer combination is not suited to continuous monitoring because the finite input resistance and the bias current of the electrometer will cause the reading to drift. However, such an arrangement may be used for spot measurements under many circumstances.

**8-3 Electrostatic Voltmeters.** This type of instrument is suitable only for the measurement of the potential of conductors to which it is connected. Electrostatic voltmeters operate by electrostatic attraction between movable and stationary metal vanes. No current flows 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 higher. The input capacitance of the meter will reduce the measured potential if the system being measured does not have a much greater capacitance.

**8-4 Field Mills.**

**8-4.1** The need to contact a charged object for measurement may be overcome by the use of a field mill. The field mill is a noncontacting device in which a shield or rotating shutter alternately exposes the sensing electrode to the electrostatic field and to a field-free region. The resulting alternating charge induced on the electrode is amplified in an AC electronic circuit and indicated on a meter. Devices of this type are called field mills, field intensity meters, generating voltmeters, or electrostatic field meters. Some field mills provide a high degree of sophistication with high accuracy.

**8-4.2** The field mill responds to the field strength (volts per unit distance) at its face. It does not measure the voltage or field strength at a different location. However, from the measurement of field strength at the field mill face, it may be possible to infer what the voltage or field strength is at a distant location. This inference is greatly dependent on the geometrical environment in which the field mill is located. A field mill is calibrated while mounted in a grounded metal plate. A known potential is applied to a parallel metal plate held at a standard distance from the meter. This parallel plate geometry provides a known uniform field strength.

**8-5 Other Noncontacting Devices.** A variety of noncontacting instruments are available that are held by hand and pointed at suspected locations of charge. Although the readout may be calibrated in volts, such hand-held meters do not really measure the voltage on a surface in front of the meter. The reading is dependent not only on the voltage of the object in front of the meter but also on the static potential of the meter itself and on the geometrical environment.

**8-6 Electroscopes.** The leaf electroscope is a simple and sensitive device that demonstrates the presence or absence of electrical charges 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.

**8-7 Neon Lamps.** A small neon lamp or 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 glows as the surface is discharged through the lamp.

## Chapter 9 Referenced Publications

**9-1** The following documents or portions thereof are referenced within this recommened practice and should be considered part of the recommendations of this document. The edition indicated for each reference is the current edition as of the date of the NFPA issuance of this document.

**9-1.1 NFPA Publications.** National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.

NFPA 32-1985, *Standard for Drycleaning Plants*

NFPA 33-1985, *Standard for Spray Application Using Flammable and Combustible Materials*

NFPA 34-1987, *Standard for Dipping and Coating Processes Using Flammable or Combustible Liquids*

NFPA 69-1986, *Standard on Explosion Prevention Systems*

NFPA 70-1987, *National Electrical Code*

NFPA 78-1986, *Lightning Protection Code*

NFPA 99-1987, *Standard for Health Care Facilities*

NFPA 321-1987, *Standard on Basic Classification of Flammable and Combustible Liquids*

NFPA 407-1985, *Standard for Aircraft Fuel Servicing*

## Appendix A Explanatory Notes

*This appendix is not a part of the recommendations of this NFPA document, but is included for information purposes only.*

**A-1-6** The following table is associated with the phenomenon variously referred to as "frictional charging," "contact/separation charging," or "tribo-charging." Electrification of two materials subject to this effect will be more pronounced the further apart they are on the list (degree of separation). (I.e., rabbit fur rubbed against cellulose nitrate would have the greatest effect. Materials adjacent to one another in the table would have the least effect.)

**A Typical Triboelectric Series**

Rabbit fur
Lucite
Bakelite
Cellulose Acetate
Glass
Quartz
Mica
Wool
Cat fur
Silk
Cotton
Wood
Amber
Resins
Metals
Polystyrene
Polyethylene
Teflon
Cellulose Nitrate

NOTE: It is certain that this series will only be reproducible in rare instances. Conditions such as cleanliness and humidity affect the series drastically. The materials at the top of the list are positive with respect to those lower in the list.

From *Electrostatics and its Applications* by A. D. Moore, John Wiley and Sons, 1973, p. 67.

## Appendix B Glossary of Terms

*This Appendix is not a part of the recommendations of this NFPA document, but is included for information purposes only.*

Words or terms found in the dictionary are not defined here. The following technical words have been defined here in terms of their usage in the field of static and their usage in this manual. Therefore, the definitions are not necessarily of a general or complete nature.

**Capacitance.** Measured in farads or fractions thereof. Capacitance is something like a tank of air. Each ounce of air pumped into the tank raises the pressure in the tank a certain amount. This amount is determined by the size or capacity of the tank. In a tiny tank the pressure rise is large when a fixed amount of air is introduced. In a large tank the pressure rise is small when the same amount of air is added. Naturally the air will remain in the tank until someone opens the valve to let it out or until the tank bursts.

To say this same thing electrically, electrons (like the air above) received by an electrically neutral body of material (tank) such as a man, a car, or an airplane, raise the voltage (pressure) at a rate depending upon the surface area and shape of the body. The voltage is determined by the surface characteristics (capacitance) of the body and the number of electrons on this surface. The larger the body the more electrons are needed to raise the voltage a specific amount. Hence the higher the capacitance of this body. Obviously a body that is large, like an aircraft, can receive and give up many electrons without a large change in voltage. Thus, it has a large capacitance. Likewise, a small body like a pin head can spare or take on only a few electrons, which will make large changes in voltage, and hence it has a small capacitance. The main difference between the electrical charge and the air explanation is that with electricity the charge remains on the outside surface of the object while the air remains inside.

Capacitance is measured in terms of "farads." Actually, the farad is so tremendous a number that it is easier to talk about millionths of a farad or "microfarads," and millionths of 1/1,000,000 of a farad or "picofarads."

**Charge.** Measured in coulombs or fractions thereof. The static charge on a body is measured by the number of separated electrons on the body (negative charge), or the number of separated electrons not on the body (positive charge). Electrons cannot be destroyed, so obviously when an electron is removed from one body it must go to another body. Thus, there are always equal and opposite charges produced [leaving behind a positive (+) void]. Since it would be awkward to say that there are 6,240,000,000,000,000,000 electrons on a body we say instead that the body has a charge of one coulomb. A coulomb is simply a name for this specific quantity of electrons. In more convenient terminology, 1 coulomb = $6.24 \times 10^{18}$ electrons. In electrostatics a much more practical unit is the microcoulomb, representing a charge of $6.24 \times 10^{12}$ electrons.

**Charge Relaxation.** The conductivity of a liquid determines the time taken for charge to dissipate to ground. When the liquid is in a grounded, conductive container the relaxation time "$\tau$" (time for the charge to fall to 1/e or 37 percent of the original charge) is given by:

$$\tau = \frac{\varepsilon \varepsilon_0}{K} \times 10^{12} \text{ seconds}$$

where $\tau$ = relaxation time (s)
$\varepsilon$ = relative permittivity of liquid
$\varepsilon_0$ = permittivity of free space ($8.85 \times 10^{-12}$ F/m)
K = conductivity of liquid (pS/m)

The lower the conductivity, the longer the relaxation time and the greater the ability of the liquid to hold a charge. If the charge is to fall to 5 percent of its original value, about three relaxation times are required and five relaxation times will reduce this to less than 1 percent of the original value. This derives from the relation:

$$Q = Q_0 \exp(-t/\tau)$$

where Q = charge at time "t"
$Q_0$ = original charge

Example: Assuming a liquid with relative permittivity of 2 and conductivity of 50 pS/m, the relaxation time given in 4-1.7 is 0.35 s. The fraction of charge remaining after one second is given by:

$$\frac{Q}{Q_0} = \exp \frac{-1}{0.35} = 0.06$$

Since the charge has fallen to about 6 percent of its original value in about 1 second, a value of conductivity of 50 pS/m or more is usually sufficient to prevent hazardous charge accumulation in grounded equipment. A liquid with conductivity of about 100 pS/m may be termed "high conductivity" for most purposes.

**Current.** Measured in amperes or fractions thereof. Just as waterflow is measured in terms of the amount of water that passes a certain point in a specific period of time (gallons per minute), so too is the flow of electrons measured by time. The flow is called current. The current is measured in terms of electrons per second, but since this number would be tremendously large, it is more convenient to measure current in terms of "coulombs per second." (*See "Charge" for a definition of coulomb.*) It was difficult to keep saying "coulombs per second" so the word "ampere" was developed instead. Thus "15 coulombs per second" became "15 amperes."

**Energy.** Measured in joules or fractions thereof. A spark is energy being expended. Energy is required to do work. The measure of energy takes several forms. Often, if it is physical energy, it is measured in foot-pounds or gram centimeters; if it is heat energy, it is measured in watt-seconds or, more easily said, in joules. A joule is quite a bit of energy. It is equivalent to being hit on the jaw by a four and one-half pound sledgehammer that has traveled about a yard in once second of time. This is quite a wallop. Static sparks do not usually have this wallop, and hence their energy is usually measured in thousandths of a joule (millijoule). A static spark needs a certain minimum amount of energy to cause trouble, as is discussed in the text.