NFPA 77

Recommended Practice
on
Static Electricity

2000 Edition

NFPA, 1 Batterymarch Park, PO Box 9101, Quincy, MA 02269-9101
An International Codes and Standards Organization

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NFPA 77

Recommended Practice on

Static Electricity

2000 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 World Fire Safety Congress and Exposition™ held May 14–17, 2000, in Denver, CO. It was issued by the Standards Council on July 20, 2000, with an effective date of August 18, 2000, and supersedes all previous editions.

This edition of NFPA 77 was approved as an American National Standard on August 18, 2000.

Origin and Development of NFPA 77

An NFPA project addressing static electricity was initiated in 1936, and a progress report was presented to the NFPA in 1937. A tentative edition of NFPA 77 was adopted in 1941. This tentative edition was further revised and officially adopted by the NFPA in 1946. Revisions were adopted in 1950, 1961, 1966, 1972, 1977, 1982, 1988, and 1993.

The 2000 edition of NFPA 77 is a completely new presentation of the subject of static electricity and its hazards. It reflects the current level of understanding of static electricity and presents considerable new information that explains the fundamental aspects of the phenomenon and recommendations for evaluating and controlling potential hazards. New information has been provided to address specific hazards of flammable gases and vapors and combustible dusts and also to address specific industrial processes and operations. The 2000 edition also provides the user with relevant properties of numerous commercially significant materials, a glossary of terms, and diagrams that show acceptable methods of bonding and grounding.

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NOTE: Membership on a committee shall not in and of itself constitute an endorsement of the Association or any document developed by the committee on which the member serves.

Committee Scope: This Committee shall have primary responsibility for documents on safeguarding against the fire and explosion hazards associated with static electricity, including the prevention and control of these hazards. This Committee shall also have primary responsibility for conductive and static-dissipative floors, except as this subject is addressed by the Committee on Health Care Facilities.

Contents

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

Information on referenced publications can be found in Chapter 10 and Appendix E.

Chapter 1 Administration

1.1 Scope.

1.1.1 This recommended practice applies to the identification, assessment, and control of static electricity for purposes of preventing fires and explosions.

1.1.2* This recommended practice does not apply directly to shock hazards from static electricity. However, application of the principles set forth in this recommended practice can reduce such shock hazards to personnel.

1.1.3* This recommended practice does not apply to the prevention and control of static electricity in hospital operating rooms or in areas where flammable anesthetics are administered or handled.

1.1.4* This recommended practice does not apply to lightning.

1.1.5* This recommended practice does not apply to stray electrical currents or to induced currents from radio frequency (RF) energy.

1.1.6* This recommended practice does not apply to fueling of motor vehicles, marine craft, or aircraft.

1.1.7* This recommended practice does not apply to cleanrooms.

1.1.8 This recommended practice does not apply to control of static electricity and static electricity hazards involved with electronic components, which have their own requirements.

1.2 Purpose. The purpose of this recommended practice is to assist the user in controlling the hazards associated with the generation, accumulation, and discharge of static electricity by providing the following:

(1) A basic understanding of the nature of static electricity
(2) Guidelines for identifying and assessing the hazards of static electricity
(3) Techniques for controlling the hazards of static electricity
(4) Guidelines for controlling static electricity in selected industrial applications

1.3 Applicability. [Reserved]

1.4 Equivalency. Nothing in this recommended practice is intended to prevent the use of systems, methods, or devices of equivalent or superior quality, strength, fire resistance, effectiveness, durability, or safety over those prescribed by this recommended practice, provided technical documentation is submitted to the authority having jurisdiction to demonstrate equivalency and the system, method, or device is approved for the purpose.

Chapter 2 Referenced Publications [Reserved]

Chapter 3 Definitions, Units, and Symbols

3.1 Definitions. The following terms are defined in this chapter for the purposes of this recommended practice.

3.1.1 Antistatic. Capable of dissipating a static electric charge at an acceptable rate.

3.1.2 Bonding. The process of connecting two or more conductive objects together by means of a conductor so that they are at the same electrical potential, but not necessarily at the same potential as the earth.

3.1.3 Breakdown Strength. The minimum voltage, measured in volts per meter of thickness, necessary to cause a spark through a solid material that is held between electrodes that produce a uniform electric field under specified test conditions.

3.1.4 Breakdown Voltage. The minimum voltage, measured in volts, necessary to cause a spark through a gas mixture between electrodes that produce a uniform electric field under specified test conditions.

3.1.5* Capacitance. The amount of charge, measured in coulombs, that must be stored on a specified body or material to raise the potential difference by 1 volt. Capacitance is measured in coulombs per volt or farads.

3.1.6 Combustible. Capable of burning.

3.1.7 Combustible Dust. Any finely divided solid material, 420 micrometers (microns, µm) or less in diameter (i.e., material that will pass through a U.S. No. 40 standard sieve), that presents a fire or explosion hazard when dispersed and ignited in air or other gaseous oxidizer.

3.1.8 Conductive. The ability to allow the flow of an electric charge; possessing a conductivity greater than 10^4 pS/m or a resistivity less than 10^8 Ω-m.

3.1.9 Conductor. A material or object that allows an electric charge to flow easily through it.

3.1.10 Grounding. The process of bonding one or more conductive objects to the ground, so that all objects are at zero (0) electrical potential; also referred to as “earthing.”

3.1.11 Ignitible Mixture. A gas–air, vapor–air, mist–air, or dust–air mixture, or combinations of such mixtures, that can be ignited by a sufficiently strong source of energy, such as a static electric discharge.

3.1.12 Inert Gas. A nonflammable, nonreactive gas that renders the combustible material in a system incapable of supporting combustion.

3.1.13 Nonconductive. The ability to resist the flow of an electric charge.

3.1.14 Nonconductor. A material or object that resists the flow of an electric charge through it.

3.1.15 Semiconductive. Possessing a conductivity between 10^2 pS/m and 10^4 pS/m or a resistivity between 10^8 Ω-m and 10^{10} Ω-m.

3.1.16 Static Electric Discharge. A release of static electricity in the form of a spark, corona discharge, brush discharge, or propagating brush discharge that might be capable of causing ignition under appropriate circumstances.

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

3.2 Symbols and Units. The following symbols are used throughout this recommended practice and are defined as follows.

A = ampere (coulombs per second). Electric current; the quantity of charge passing per second through a given point.

C = capacitance (farads)

d = diameter (meters)

e = 2.718 [base of Napierian (natural) logarithms]

E = V/m = electric field strength (volts per meter)

ε = dielectric constant of a material

$\varepsilon_0 = 8.845 \times 10^{-12}$ farads per meter (electrical permittivity of a vacuum)

$\varepsilon\varepsilon_0$ = electrical permittivity of a material (farads per meter)

I_s = streaming current (amperes)

κ = liquid conductivity (picosiemens per meter)

μ = ion mobility (square meters per volt-second)

μm = micrometers (microns) = 10^{-6} meters

Ω-m = electrical resistivity (ohm-meter)

P = pressure (millimeters of mercury)

Q = quantity of electrical charge (coulombs)

R = electrical resistance (ohms)

ρ = volume resistivity (ohm-meters)

S = electrical conductance (siemens)

t = elapsed time (seconds)

τ = charge relaxation time constant (seconds)

v = flow velocity (meters per second)

V = electrical potential difference (volts)

W = energy or work done (joules)

Chapter 4 Fundamentals of Static Electricity

4.1 General.

4.1.1 The most common experiences of static electricity are the crackling and clinging of fabrics as they are removed from a clothes dryer or the electric shock felt as one touches a metal object after walking across a carpeted floor or stepping out of an automobile. Nearly everyone recognizes that these phenomena occur mainly when the atmosphere is very dry, particularly in winter. To most people, they are simply an annoyance. In many industries, particularly those where combustible materials are handled, static electricity can cause fires or explosions.

4.1.2 The word *electricity* is derived from the ancient Greek word for amber, *elektron.* The phenomenon of electrification was first noticed when pieces of amber were rubbed briskly. For centuries, the word *electricity* had no meaning other than the ability of some substances to attract or repel lightweight objects after being rubbed with a material like silk or wool. 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 (current) electricity were discovered, the term *static* came into use as a means of distinguishing a charge that was at rest from one that was in motion. However, today the term is used to describe phenomena that originate from an electric charge, regardless of whether the charge is at rest or in motion.

4.1.3 All materials, whether solid or fluid, are composed of various arrangements of atoms. The atoms are composed of positively charged nuclear components that give them mass, surrounded by negatively charged electrons. Atoms can be considered electrically neutral in their normal state, meaning that there are equal amounts of positive and negative charge present. They can become charged when there is an excess or a deficiency of electrons relative to the neutral state. Electrons are mobile and of insignificant mass and are the charge carriers most associated with static electricity.

4.1.4 In materials that are conductors of electricity, such as metals, electrons can move freely. In materials that are insulators, electrons are more tightly bound to the nuclei of the atoms and are not free to move. Examples of insulators include the following:

(1) Nonconductive glass
(2) Rubber
(3) Plastic resins
(4) Dry gases
(5) Paper
(6) Petroleum fluids

The mobility of electrons in materials known as semiconductors is freer than in insulators but is still less than in conductors. Semiconductive materials are commonly characterized by their high electrical resistance, which can be measured with a megohmmeter.

4.1.5 In otherwise insulating fluids, an electron can separate from one atom and move freely or attach to another atom to form a negative ion. The atom losing the electron then becomes a positive ion. Ions are charged atoms and molecules.

4.1.6 Unlike charges attract each other and the attractive force can draw the charges together, if the charges are mobile. The energy stored is the result of the work done to keep the charges separated by a finite distance.

4.1.7 Separation of charge cannot be prevented absolutely, because the origin of the charge lies at the interface of materials. When materials are placed in contact, some electrons move from one material to the other until a balance (equilibrium condition) in energy is reached. This charge separation is most noticeable in liquids that are in contact with solid surfaces and in solids in contact with other solids. The flow of clean gas over a solid surface produces negligible charging.

4.1.8 The enhanced charging that results from rubbing materials together (triboelectric charging) is the result of exposing surface electrons to a broad variety of energies in an adjacent material, so that charge separation is more likely to take place. The breakup of liquids by splashing and misting results in a similar charge separation. It is only necessary to transfer about one electron for each 500,000 atoms to produce a condition that can lead to a static electric discharge. Surface contaminants at very low concentrations can play a significant role in charge separation at the interface of materials. *[See Figures 4.1.8(a) and (b).]*

FIGURE 4.1.8(a) Typical charge generation by bulk motion of insulating materials. *(Walmsley, 1992, p. 19.)*

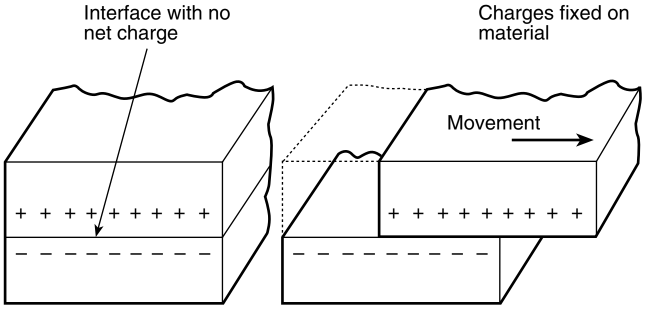
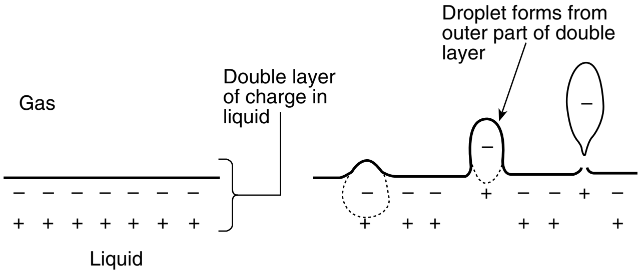


FIGURE 4.1.8(b) Typical charge generation by atomization. *(Walmsley, 1992, p. 19.)*



4.1.9 Conductive materials can become charged when brought near a highly charged surface. Electrons in the conductive material are either drawn toward or forced away from the region of closest approach to the charged surface, depending on the nature of the charge on that surface. If the conductive material is then touched to ground or to a third object, additional electrons can pass to or from ground or the object. If contact is then broken and the conductive material and charged surface are separated, the charge on the isolated conductive object changes. The net charge that is transferred is called *induced charge. [See Figures 4.1.9(a), (b), (c), and (d).]*

4.1.10 The separation of charge on a neutral isolated conductor and its distribution near a charged insulating surface will produce electrical stresses near the point of closest approach. Sharp edges on the conductor can yield a localized electrical breakdown of the gas stream, known as *corona*, or an electric spark across the gap. Either of these events can transfer charge between the materials, leaving the isolated conductor charged. Such a transfer occurs, for example, when a person wearing nonconductive shoes receives a static electric shock by contacting the metal frame supporting a highly charged web. As a result, the person acquires a net static electric charge and can receive a second shock after leaving the area by touching a grounded metal object, thereby allowing the acquired charge to flow to earth.

4.1.11 Charge can also be imparted to a surface or into the bulk of a material by directing a stream of electrons or ions against it. If the surface is not conductive or is conductive but isolated from ground, the charge delivered by the bombarding stream will remain after the stream stops.

4.1.12 Charge can also be injected into a stream of nonconductive fluid by submerging within the stream a pointed electrode on which a high voltage has been impressed.

FIGURE 4.1.9(a) Charged insulator with field lines shown. *(Pratt, 1997, p. 29.)*

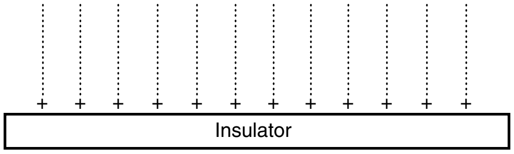


FIGURE 4.1.9(b) Induced charge on conductor; the charge remains on the conductor as the conductor is removed from contact with the insulator. *(Pratt, 1997, p. 29.)*

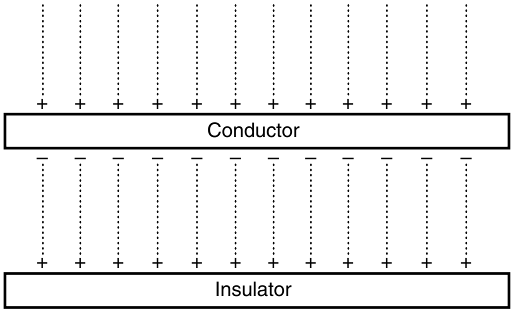


FIGURE 4.1.9(c) Discharge of free charge from a conductor. *(Pratt, 1997, p. 29.)*

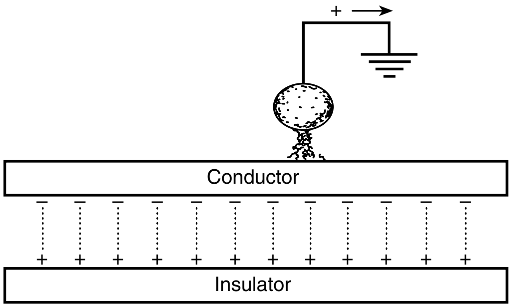
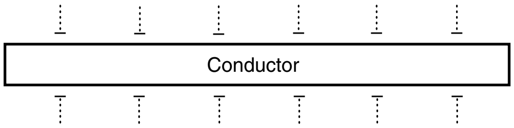


FIGURE 4.1.9(d) Conductor, removed from an insulator, carrying a charge.



4.2 Accumulation and Dissipation of Charge.

4.2.1 A static electric charge will accumulate whenever the rate at which charges separate exceeds the rate at which charges recombine. Work must be done to separate charges, and there is a tendency for the charges to return to a neutral state. The potential difference, that is, the voltage, between any two points is the work per unit charge that would have to be done to move the charges from one point to the other. This work depends on the physical geometry (i.e., shape, size, nature of materials, and location of objects) of the particular system and can be expressed by the following equation:

$$C = \frac{Q}{V}$$

where:

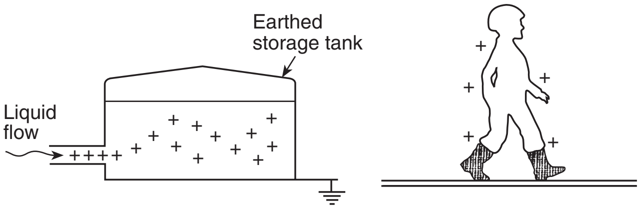
C = capacitance (farads)

Q = charge that has been separated (coulombs)

V = potential difference (volts)

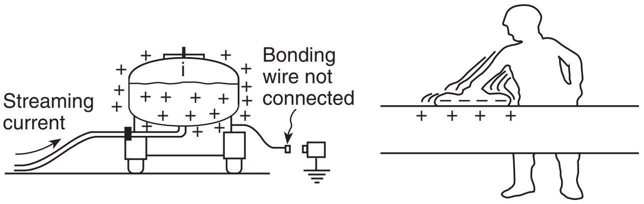
Typical examples of accumulation are illustrated in Figure 4.2.1.

FIGURE 4.2.1 Typical examples of charge accumulation. ***(Walmsley, 1992, p. 37.)***



(a) Charge accumulation on low conductivity liquids

(c) Charge accumulation on a person on an insulating floor or wearing insulating footwear



(b) Charge accumulation on an insulated conductor

(d) Charge accumulation on insulating solids (e.g., rubbing an insulating pipe)

4.2.2 Separation of electric charge might not, in itself, be a potential fire or explosion hazard. There must be a discharge or sudden recombination of the separated charges to pose an ignition hazard. One of the best protections from static electric discharge is a conductive or semiconductive path that allows the controlled recombination of the charges.

4.2.3 In static electric phenomena, charge is generally separated by a resistive barrier, such as an air gap or insulation between the conductors or by the insulating property of the materials being handled or processed. In many applications, particularly those where the materials being processed are charged insulators (nonconductors), it is not easy to measure the charges or their potential differences.

4.2.4 When recombining of charges occurs through a path that has electrical resistance, the process proceeds at a finite rate, t/τ, and is described by the *relaxation time* or *charge decay time*, τ. This relaxation process is typically exponential and is expressed by the following equation:

$$Q_t = Q_0 e^{-t/\tau}$$

where:

Q_t = charge remaining at time t (coulombs)

Q_0 = charge originally separated (coulombs)

e = 2.718 (base of natural logarithms)

t = elapsed time (seconds)

τ = time constant (seconds)

The rate of charge recombination depends on the capacitance of the material and its resistance and is expressed as follows:

$$\tau = RC$$

where:

τ = time constant (seconds)

R = resistance (ohms)

C = capacitance (farads)

For bulk materials, the relaxation time is often expressed in terms of the volume electrical resistivity of the material and its electrical permittivity as follows:

$$\tau = \rho\varepsilon\varepsilon_0$$

where:

τ = time constant (seconds)

ρ = resistivity (ohm-meters)

$\varepsilon\varepsilon_0$ = electrical permittivity (farads per meter)

4.2.5 The exponential decay model described in 4.2.4 is helpful in explaining the recombination process, but is not necessarily applicable to all situations. In particular, nonexponential decay is observed when the materials supporting the charge are certain low conductivity liquids or powders composed of combinations of insulating, semiconductive, and conductive materials. The decay in these cases is faster than the exponential model predicts.

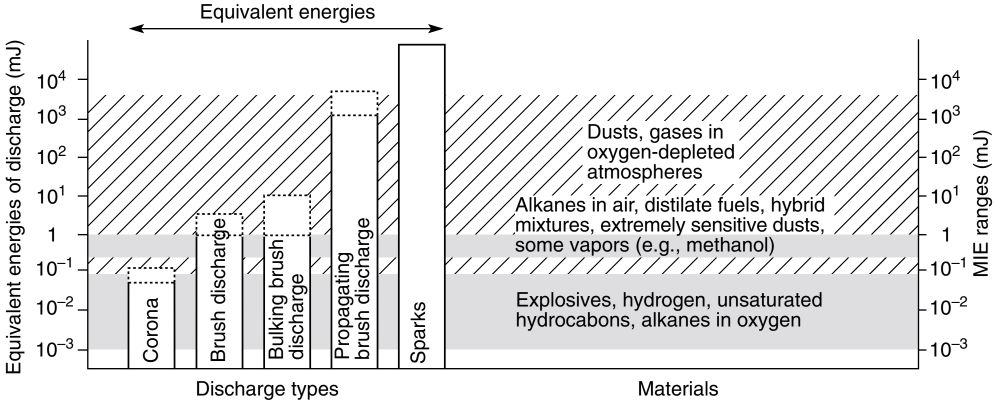
4.2.6 Dissipation of static electric charges can be effected by modifying the volume or surface resistivity of insulating materials with antistatic additives, by grounding isolated conductors, or by ionizing the air near insulating materials or isolated conductors. Air ionization involves introducing mobile electric charges (positive, negative, or both) into the air around the charged objects. These ions are attracted to the charged objects until they become electrically neutral. The ion current in the air serves as the mechanism that brings the neutralizing charge to the otherwise bound or isolated charge.

4.3 Discharge of Static Electricity and Ignition Mechanisms.

4.3.1 General. As electric charge accumulates through separation, there will be an increase in the electrical forces trying to restore a neutral condition by reuniting those charges in the form of a static electric discharge. Many types of discharges can occur, and these are illustrated broadly in Figure 4.3.1. For a static electric discharge to be a source of ignition, the following four conditions must be met:

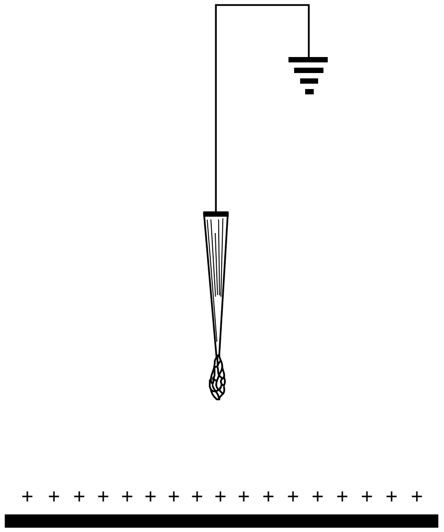
(1) An effective means of separating charge must be present.
(2) A means of accumulating the separated charges and maintaining a difference of electrical potential must be available.
(3) A discharge of the static electricity of adequate energy must occur.
(4) The discharge must occur in an ignitible mixture.

FIGURE 4.3.1 Approximate energies of types of discharges compared with minimum ignition energies (MIE) of typical combustible materials. ***(Adapted from Walmsley, 1992, p. 26.)***



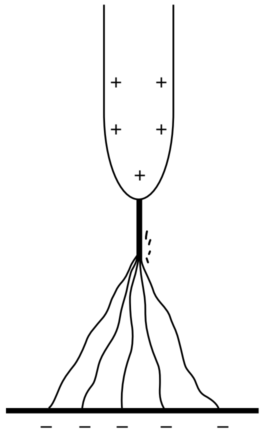
4.3.2 Corona Discharge. Corona is an electrical discharge in the microampere range that results from a localized electrical needle-shaped breakdown of gases by charges on surfaces such as sharp edges, points, and wires. The charges can arise on conductors at high voltages or on grounded conductors that are situated near a charged surface. Corona is accompanied by a faint luminosity. *(See Figure 4.3.2.)*

FIGURE 4.3.2 Corona discharge. ***(Pratt, 1997, p. 32.)***



4.3.2.1 In most cases, the energy density of corona discharge is very low. Consequently, the hazard from corona discharge is small. Where corona discharge is more intense, prebreakdown streamers called *brush discharges* occur. These appear as random filaments of light that make faint hissing or frying sounds. Brush discharges that originate on needle-like tips with radii smaller than 1 mm do not, in general, lead to ignition. Discharges from blades, however, can ignite mixtures that have very low ignition energies, such as hydrogen–air or carbon disulfide–air mixtures. Gas–air and vapor–air mixtures can be ignited if brush discharges originate from elements with edge diameters greater than 5 mm, or from a rod with a hemispherical end, such as a human finger. *(See Figure 4.3.2.1.)*

FIGURE 4.3.2.1 Brush discharge. ***(Adapted from Walmsley, 1992, p. 27.)***



4.3.2.2 Sharp edges, corners, and projections (e.g., those with an edge diameter of 5 mm or less) that point toward charged surfaces should be identified. These sharp regions concentrate the charge, providing intense, localized stresses that can lead to electrical corona and sparks.

4.3.3 Sparks Between Conductors.

4.3.3.1 Sparks from ungrounded charged conductors, including the human body, are responsible for most fires and explosions ignited by static electricity. Sparks are typically intense capacitive discharges that occur in the gap between two charged conducting bodies, usually metal. The energy of a spark discharge is highly concentrated in space and in time.

4.3.3.2 The ability of a spark to produce ignition is governed largely by its energy, which will be some fraction of the total energy stored in the system.

4.3.3.3 The energy of a spark can be determined from the capacitance of the conductive system and the electrical potential or from the quantity of charge separated from the conductors and is expressed by the following equations:

$$W = \frac{1}{2}CV^2$$

$$W = \frac{1}{2}\frac{Q^2}{C}$$

where:

W = energy (joules)

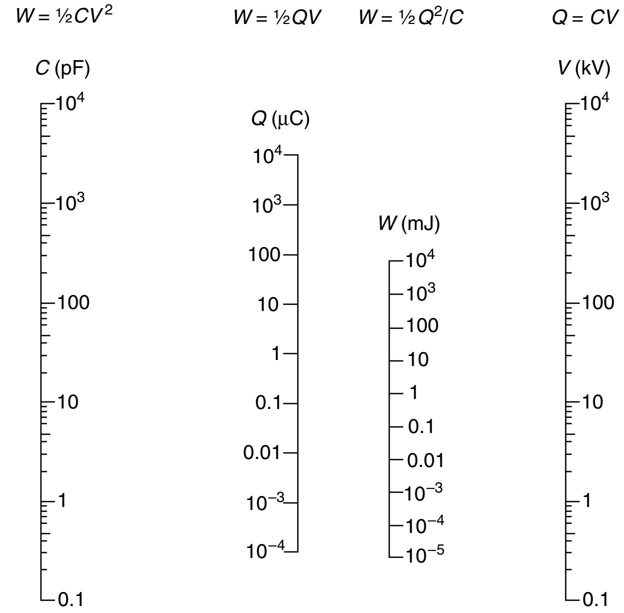
C = capacitance (farads)

V = potential difference (volts)

Q = charge (coulombs)

The relationships are shown in Figure 4.3.3.3.

FIGURE 4.3.3.3 Nomograph for estimating energy in a capacitive spark discharge. ***(Pratt, 1997, p. 113.)***



4.3.3.4* To be capable of causing ignition, the energy released in the discharge must be at least equal to the minimum ignition energy (MIE) of the ignitible mixture. Other factors, such as the shape of the charged electrodes and the form of discharge, influence conditions for the static electric discharge and its likelihood of causing ignition.

4.3.3.5 Most gases and vapors of saturated hydrocarbons require about 0.25 mJ of energy for spark discharge ignition, assuming optimum mixtures with air. Unsaturated hydrocarbons can have lower MIEs. Discussion of MIEs for specific materials can be found in Chapters 7 through 9.

4.3.3.6 Mists, dusts, and fibers usually require MIEs that are one or two orders of magnitude greater than those for gases and vapors. Note that for any given particulate material, the MIE diminishes rapidly with decreasing particle size.

4.3.3.7 The ignition energies for gases, vapors, and dusts are reduced by an increase in the oxygen concentration relative to that for air. Likewise, ignition energies are increased by a decrease in oxygen concentration.

4.3.4 Hybrid Mixtures. Where two or more flammable materials of different phases (e.g., a dust and a vapor) are present in the same mixture, the mixture is known as a *hybrid.* Tests have shown that adding a flammable gas to a dust suspension can greatly lower the ignition energy of the dust. This phenomenon is especially true when the gas is present at a concentration below its lower flammable limit or the dust is below its minimum explosable concentration. Such hybrid mixtures can sometimes be ignited even if both components are below their respective lower limits. A hybrid mixture can be formed by:

(1) Vapor desorption from particulates (such as in resin product receivers)
(2) Reaction of particulates with atmospheric moisture that produces a flammable gas
(3) Introduction of a dust into a flammable vapor atmosphere (such as adding a dust or powder to a flammable liquid)

In such instances, the hybrid mixture can be ignited at the MIE of the most easily ignited component.

4.3.5 Static Electric Discharge from the Human Body.

4.3.5.1 The human body is a good electrical conductor and numerous incidents have resulted from static electric discharges from people.

4.3.5.2 If a person is insulated from ground, that person can accumulate a significant charge by walking on an insulating surface, by touching a charged object, by brushing surfaces while wearing nonconductive clothing, or by momentarily touching a grounded object in the presence of charges in the environment. During normal activity, the potential of the human body can reach 10 kV to 15 kV, and the energy of a possible spark can reach 20 mJ to 30 mJ. By comparing these values to the MIEs of gases or vapors, the hazard is readily apparent.

4.3.6 Discharges Between Conductors and Insulators.

4.3.6.1 Sparks often occur between conductors and insulators. Examples of such occurrences include situations in which plastic parts and structures, insulating films and webs, liquids, and particulate material are handled. The charging of these materials can result in surface discharges and sparks, depending on the accumulated charge and the shape of nearby conductive surfaces. The variable (both in magnitude and polarity) charge density observed on insulating surfaces is the effect of these discharges spreading over a limited part of the insulating surface.

4.3.6.2 Even with the use of static electricity neutralizers, some charges will remain in certain areas, but these will typically not be hazardous if there is no mechanism by which they can accumulate. However, a dangerous (i.e., ignition-capable) static electric charge can result due to concentration of individual charges. Examples are stacking or nesting of empty plastic containers, winding film onto a roll or drum, and filling a vessel with a nonconductive liquid or powder.

4.3.7 Discharge on the Surface of an Insulator Backed by a Conductor. A surface coated with a thin (less than 8 mm) layer of an insulating material will act as a capacitor to store charge. At sufficiently high charge levels (i.e., greater than 250 $\mu C/m^2$), a branching discharge will be observed on the surface of the coating. This branching discharge is called a *propagating brush discharge.* Alternatively, an electrical breakdown through the layer can occur. The energy stored in the coating can be as high as several joules per square meter, so the energy of the discharge, however distributed in space, can be sufficient to ignite gas–air, vapor–air, and dust–air mixtures. *(See Figure 4.3.7.)*

FIGURE 4.3.7 Propagating brush discharge. ***(Pratt, 1997, p. 35.)***

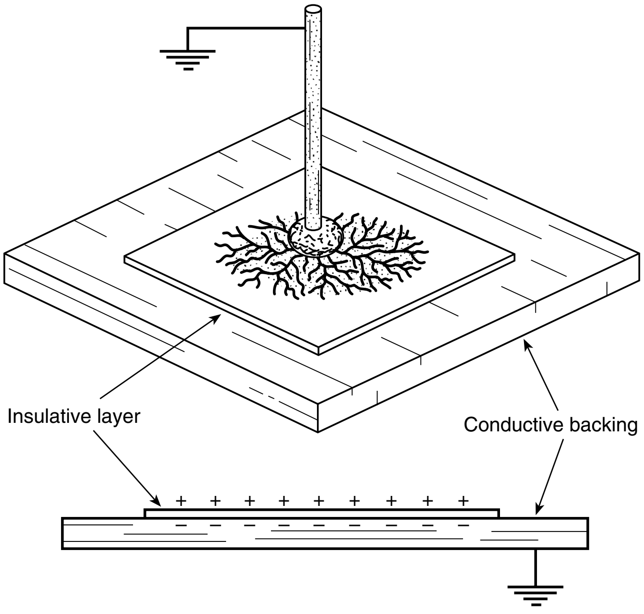
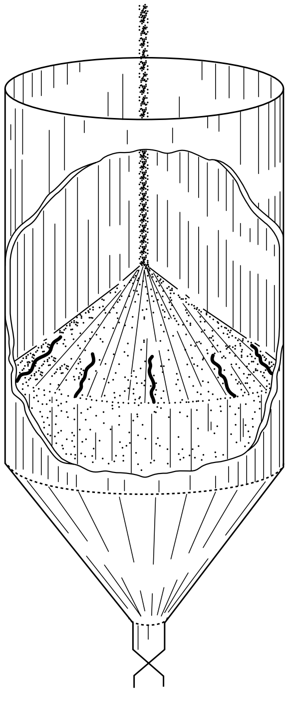


FIGURE 4.3.8 Bulking brush discharge during filling of silos with a bulk powder.



4.3.8* Discharges During Filling Operations. During filling of large silos with powders, granules, and pellets, surface flashes up to a meter in length have been observed. These discharges, called *bulking brush (cone) discharges,* are accompanied by a crackling sound capable of being heard above the noise of the material transfer. Bulking brush discharges have a maximum effective energy of 10 mJ to 25 mJ and are believed responsible for dust explosions in grounded silos. Similar discharges are observed during the filling of tank vehicles with nonconductive liquids. In this case, the phenomenon is known as a *surface streamer* or *go-devil. (See Figure 4.3.8.)*

Chapter 5 Evaluating the Hazard of Static Electricity

5.1 General.

5.1.1 The following are two basic steps in evaluating static electricity hazards:

(1) Identifying locations where charge separates and accumulates
(2) Assessing the ignition hazards at these locations

The basic process is outlined in Figure 5.1.1.

5.1.2 On-site evaluation or survey of the process should be made to identify any ungrounded conductive objects, including personnel, and any materials that could serve as electrical insulators and could interfere with proper bonding and grounding. The survey should identify those locations that might pose a static electricity hazard, even if there is no evidence of accumulation of charge at the time of the evaluation.

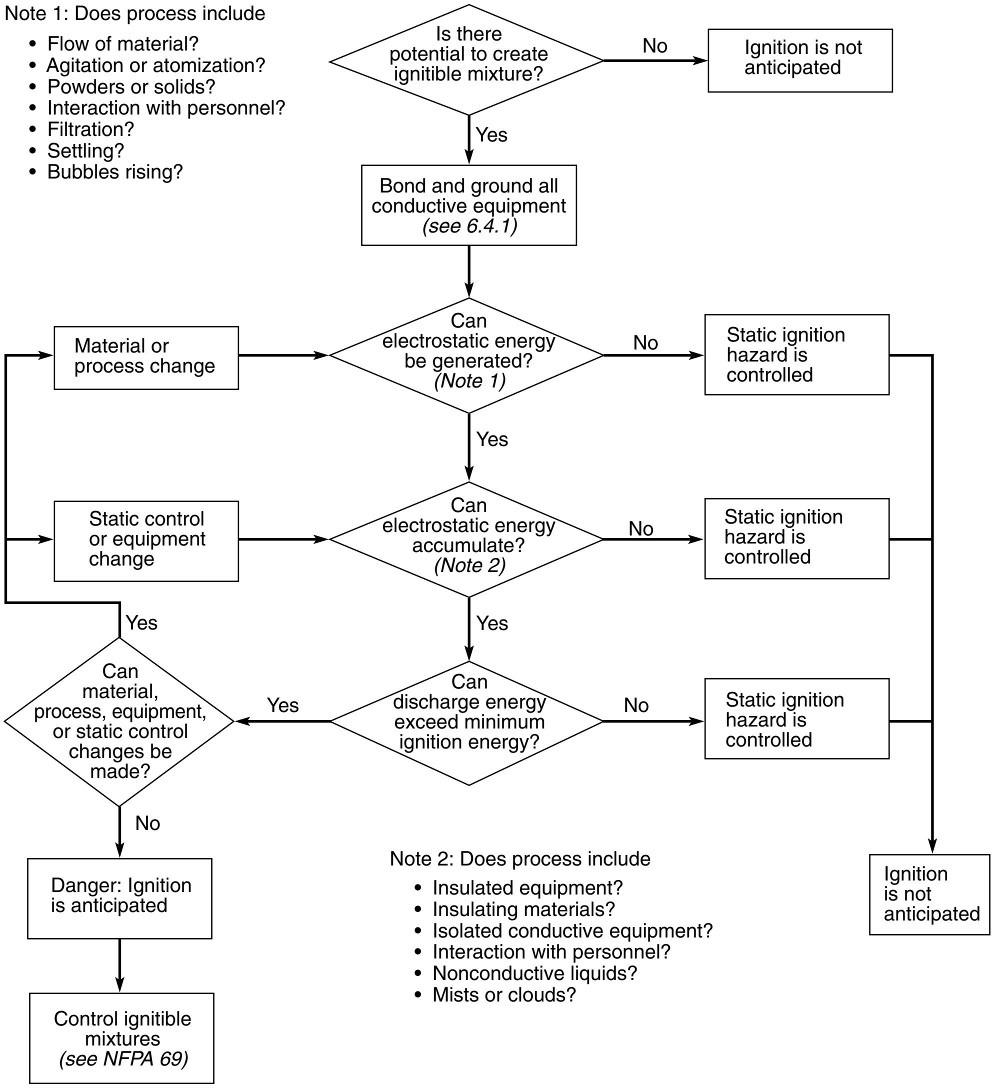
5.1.2.1 Special attention should be given to insulating materials that are handled or processed. Each process operation should be considered separately and attention should be given to the likely range of exposure of the materials. For example, changes in temperature and relative humidity can significantly influence the bulk conductivity and surface conductivity of materials.

5.1.2.2 It is often helpful to complete a design review of the operation, process, or machine and a visual survey of the area first. An on-site instrumented evaluation should then be conducted during actual operating conditions to determine the nature and magnitude of any static electricity hazards present.

WARNING

> During an audit, precautions should be taken that are consistent with the equipment and the materials in the area where measurements are to be taken. The primary ignition hazard comes from introducing a grounded electrode, such as the housing of a field meter *(see Section 5.4)*, into the vicinity of a charged surface, thus providing a route for a static electric discharge. The surface being measured should always be approached slowly while observing the meter's response. Extreme care should be taken so that neither instruments nor testing techniques cause ignition of flammable atmospheres. Appropriate safe work practices should be employed when taking measurements in and around physical hazards such as moving belts, webs, and pulleys.

FIGURE 5.1.1 Flow chart for determining static electric ignition hazard.



5.2 Measuring a Static Electric Charge. A meaningful evaluation requires using an appropriate instrument, using the instrument according to the manufacturer's instructions, maintaining calibration of the instrument, and interpreting the measurements according to the manufacturer's recommendations.

5.3 Measuring the Charge on a Conductor.

5.3.1 The voltage on a conductor is proportional to the charge it supports and is expressed by the following equation:

$$V = \frac{Q}{C}$$

where:

V = potential difference (volts)

Q = charge supported by the conductor (coulombs)

C = capacitance of the conductor (farads)

5.3.2 The voltage on a conductor can be measured by direct contact using a voltmeter, provided the impedance of the voltmeter is high enough so that it does not discharge the conductor and the capacitance is small enough so that it does not collect a significant charge from the conductor. An electrostatic voltmeter with input impedance greater than 10^{12} ohms can be used for measuring voltages on most ungrounded conductors. Since conductors have the same voltage at every point on their surface, it is not important where the test probe of the voltmeter touches the surface of the conductor.

5.4 Measuring the Charge on a Nonconductor.

5.4.1 The charge on a nonconductor cannot be measured using a direct contact electrostatic voltmeter. A noncontact electrostatic voltmeter, or field meter, must be used. A noncontact electrostatic voltmeter senses the strength of the static electric field from the net charge on or in the nonconductor. The field strength is proportional to the static electric force per unit charge and it describes the electric forces present near a charged object. For practical purposes, an electric field is the force that one experiences or measures around a charged object.

5.4.2 Field meters are calibrated to measure the electric field in units of volts per unit distance, typically in kilovolts per meter. In most cases, the measurements are proportional to the net static electric charge on the object being measured. Field meters are called *field mills* or *charge locators*, depending on their principle of operation and level of sophistication. Since the charge density on or in a nonconductor is typically not uniform, measurements should be taken at several locations.

5.4.3 Charged nonconductors exist in many forms, such as sheets, films, webs, powders, liquids, process rolls, and extrusions. Charges on these materials and objects will produce electric fields that will be influenced by the instrument, by the observer, and by other nearby conductive, semiconductive, or insulating materials. As a result, the electric field measured by the instrument will generally be different from the electric field present before the instrument was introduced. This phenomenon is a result of a change in capacitance.

5.4.4 The forces between electric charges exhibit themselves at a distance. For this reason, the effects of accumulated charge can be observed as the charged objects are approached. For example, the hands and arms of a person who approaches a highly charged object will tingle and might even draw a spark as the surface of the skin and the hair become "charged." Sometimes these observations and sparks provide the first indication that a potentially hazardous condition exists. This charging of the human body can happen even if the person is well grounded.

5.5 General Practices.

5.5.1 The primary instrument for locating a charge on either a conductor or a nonconductor is the noncontact voltmeter or field meter. As its name implies, the instrument does not contact the charged surface directly. Rather, it senses the magnitude and the polarity of the electric field that exists *at its sensing aperture.* As stated in 5.4.3, the instrument and its sensing aperture disturb the electric field around the charge to be measured, so the meter reading does not accurately indicate the actual magnitude of the field when the meter is not present. Aside from this deficiency, the field meter is an inexpensive and valuable tool for locating a static electric charge.

5.5.2 In some cases, primarily cases involving flowing liquids and flowing bulk solids, it is easier to collect a sample of the charged material in an isolated vessel or cup, referred to as a *Faraday cup,* and to use an electrometer to measure the streaming current or net charge flowing to the cup receiving the charged material.

5.5.3 The proper use of instruments to evaluate the magnitude of charge accumulation in specific applications is further discussed in Chapters 7 through 9.

5.6 Measuring the Accumulation and Relaxation of Charge.

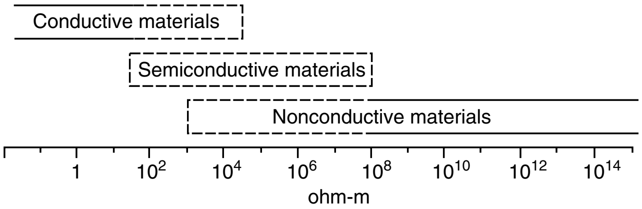
5.6.1 Measuring the rate of accumulation and relaxation of static electric charge involves measuring changing potential differences or currents.

5.6.2 Field meters and dedicated charge decay monitors can be used to observe charge relaxation under conditions of prescribed initial voltages on conductors and nonconductors.

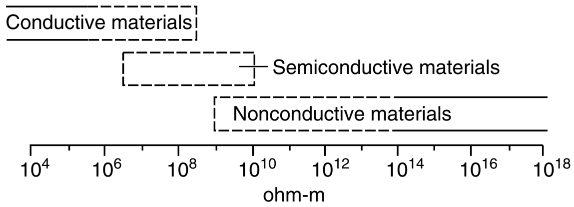
5.6.3 Leakage currents down to about 10^{-13} A can be measured from isolated conductors using commercially available electrometers. The isolated conductor can be a Faraday cup containing a bulk solid or fluid.

5.7 Measuring the Resistivity of Materials. Electrical resistivity of materials often consists of volume (bulk) and surface components. In electrostatic processes, the approximate ranges of resistivities that define materials as insulating, semiconductive (antistatic), or conductive are summarized in Figure 5.7.

FIGURE 5.7 Ranges of volume and surface resistivities. ***(Walmsley, 1992, p. 138.)***



(a) Volume resistivity



(b) Surface resistivity

5.7.1 Electric charges can be conducted from a solid, liquid, or powder, either across the surface or through the material.

5.7.2 The volumetric resistivity of a material can be determined by applying a potential difference across a sample of known cross section and monitoring the current through the cross section.

5.7.3 Adsorbed material, particularly water vapor, and compaction of materials are known to lower the resistivity of materials. The resistivity of many materials also has been found to vary with the applied potential difference and with the duration of the test. Various designs of cells used to measure resistivity have been developed into standard test configurations that are applicable to specific kinds of samples. Appropriate test procedures include the following:

(1) ASTM D 257, *Standard Test Methods for DC Resistance or Conductance of Insulating Materials,* 1999
(2) JIS B 9915, *Measuring Methods for Dust Resistivity (with Parallel Electrodes)*
(3) CENELEC EN 61241-2-2, *Electrical Apparatus for Use in the Presence of Combustible Dust — Part 2: Test Methods; Section 2: Method for Determining the Electrical Resistivity of Dust in Layers,* 1995

5.8 Assessment of Bonding and Grounding.

5.8.1 As defined in Chapter 3, bonding is a process whereby two or more conductive objects are connected together by means of a conductor, so that they are at the same electrical potential; that is, the voltage difference between the objects is zero (0). The objects might or might not be at the same potential as the earth. In fact, a considerable potential difference between the objects and the earth could exist.

Grounding is the process of connecting the conductive objects to the earth, so that they are all at zero (0) electrical potential.

In both cases, the intent is to eliminate the occurrence of a static electric spark.

5.8.2 Identification of conductive equipment and objects within a process is critical for successful bonding and grounding. Periodic inspection and testing of bonding and grounding systems is equally important. Proper inspection and testing will ensure that the chances for a static electric charge to accumulate are minimized.

5.8.3 The resistance to ground of the bonding or grounding path is important, not only to ensure relaxation of the static electric charge, but also to maintain worker safety and satisfy other purposes, such as those for lightning protection and electrical system shock protection. Practices that constitute proper resistance to ground will vary from application to application. Chapters 6 through 9 provide examples of acceptable grounding practices.

5.8.4 The resistance to ground is measured with a common ohmmeter or megohmmeter.

5.9 Measuring Spark Energies. The discharge energy for conductors is determined from the voltage on the conductor and its capacitance and is expressed by the following equation, which is also given in 4.3.3.3:

$$W = \frac{1}{2}CV^2$$

$$W = \frac{1}{2}\frac{Q^2}{C}$$

where:

W = energy (joules)

C = capacitance (farads)

V = potential difference (volts)

Q = charge (coulombs)

A capacitance meter can often be used to measure electrostatic charge storage capacity when the charge is stored on a conductive element.

5.10 Measuring Ignition Energies. Any combustible solid (dust), liquid (vapor), or gas should be considered for its potential as an ignitible atmosphere in the presence of discharges of static electricity. This requires determining the MIE of the material. Some data on MIE can be found in Appendix B. Standardized test equipment and procedures have been developed for measuring MIEs of particulate and gaseous materials. The equipment is highly specialized and requires trained technicians for its operation. Typically, the equipment is operated and maintained by specialized testing firms.

Chapter 6 Control of Static Electricity Hazards

6.1 General.

6.1.1 The objective of controlling a static electricity hazard is to provide a means whereby charges, separated by whatever cause, can recombine harmlessly before discharges can occur.

6.1.2 Ignition hazards from static electricity can be controlled by the following methods:

(1) Removing the ignitible mixture from the area where static electricity could cause an ignition-capable discharge
(2) Reducing charge generation, charge accumulation, or both by means of process or product modifications
(3) Neutralizing the charges

Grounding isolated conductors and air ionization are primary methods of neutralizing charges.

6.2 Control of Ignitible Mixtures by Inerting Equipment, by Ventilating, or by Relocating Equipment.

6.2.1 General. Despite efforts to prevent accumulation of static electric charges, which should be the primary aim of good design, many operations involving the handling of nonconductive materials or nonconductive equipment do not lend themselves to engineered solutions. It then becomes desirable or essential, depending on the nature of the materials involved, to provide other measures, such as inerting the equipment, ventilating the equipment or the area in which it is located, or relocating the equipment to a safer area.

6.2.2 Inerting. Where an ignitible mixture is contained, such as in a processing vessel, the atmosphere can be made oxygen deficient by introducing enough inert gas (e.g., nitrogen or combustion flue gas) to make the mixture nonignitible. This technique is known as *inerting*. When operations are normally conducted in an atmosphere containing a mixture above the upper flammable limit, it might be practical to introduce the inert gas only during those periods when the mixture passes through its flammable range. NFPA 69, *Standard on Explosion Prevention Systems*, contains requirements for inerting systems.

6.2.3 Ventilating. Mechanical ventilation can be used to dilute the concentration of a combustible material to a point well below its lower flammable limit (LFL) in the case of a gas or vapor or below its minimum explosible concentration (MEC) in the case of a dust. Usually, this means dilution to a concentration at or below 25 percent of the lower limit. Also, by properly directing the air movement, it might be practical to prevent the material from approaching an area of operation where an otherwise uncontrollable static electricity hazard exists.

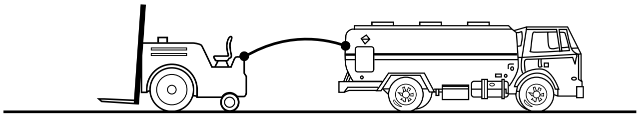
6.2.4 Relocating Equipment. Where equipment that can accumulate a static electric charge is unnecessarily located in a hazardous area, it might be possible to relocate it to a safe location rather than to rely on other means of hazard control.

6.3 Control of Static Charge Generation. Electric charges separate when materials are placed in contact and are pulled apart. Reducing process speeds and flow rates will reduce the rate of charge generation. Examples of such charge separation are found where plastic parts and structures, insulating films and webs, liquids, and particulate material are handled. If the material flows at a slow enough rate, a hazardous level of excess charge will not normally accumulate. This means of static electricity control might not be practical due to processing requirements. *(See Chapters 7 through 9 for recommended practices in specific applications.)*

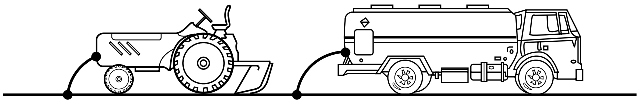
6.4 Charge Dissipation.

6.4.1 Bonding and Grounding. Bonding is used to minimize the potential difference between conductive objects, even when the resulting system is not grounded. Grounding (i.e., earthing), on the other hand, equalizes the potential difference between the objects and the earth. The relationship between bonding and grounding is illustrated in Figure 6.4.1.

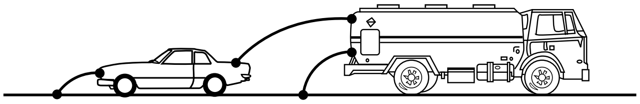
FIGURE 6.4.1 Bonding and grounding.



Bonding



Grounding



Bonding and grounding

6.4.1.1 A conductive object can be grounded by a direct conductive path to the earth or by bonding it to another conductive object that is already connected to the ground. Some objects are inherently bonded or inherently grounded because of their contact with the ground. Examples of inherently grounded objects are underground metal piping or large metal storage tanks resting on the ground.

6.4.1.2 The total resistance between a grounded object and the soil is the sum of the individual resistances of the ground wire, its connectors, other conductive materials along the intended grounding path, and the resistance of the ground electrode (i.e., ground rod) to the soil. Most of the resistance in a ground connection exists between the ground electrode and the soil. This ground resistance is quite variable, since it depends on the area of contact, the resistivity of the soil, and the amount of moisture present in the soil.

6.4.1.3 To prevent the accumulation of static electricity in conductive equipment, the total resistance of the ground path to earth should be sufficient to dissipate charges that are otherwise likely to be present. A resistance of 1 megohm (10^6 ohms) or less is generally considered adequate. Where the bonding/grounding system is all metal, resistance in continuous ground paths will typically be less than 10 ohms. Such systems include multiple component systems. Greater resistance usually indicates the metal path is not continuous, usually because of loose connections or corrosion. A grounding system that is acceptable for power circuits or for lightning protection is more than adequate for a static electricity grounding system.

Appendix C contains diagrams of various grounding devices, connections, and equipment.

6.4.1.4 Where wire conductors are used, the minimum size of the bonding or grounding wire is dictated by mechanical strength, not by its current-carrying capacity. Stranded or braided wires should be used for bonding wires that will be connected and disconnected frequently. *(See Appendix C for additional information.)*

6.4.1.5 Grounding conductors can be insulated (e.g., a jacketed or plastic-coated cable) or uninsulated (i.e., bare conductors). Uninsulated conductors are recommended, because it is easier to detect defects in them.

6.4.1.6 Permanent bonding or grounding connections can be made by brazing or welding. Temporary connections can be made using bolts, pressure-type ground clamps, or other special clamps. Pressure-type clamps should have sufficient pressure to penetrate any protective coating, rust, or spilled material to ensure contact with the base metal.

6.4.1.7 Workers should only be grounded through a resistance that limits the current to ground to less than 3 mA for the range of voltages experienced in the area. This method is called *soft grounding* and is used to prevent injury from an electric shock from line voltages or stray currents.

6.4.2 Humidification.

6.4.2.1 The surface resistivity of many materials can be controlled by the humidity of the surroundings. At humidities of 65 percent and higher, the surface of most materials will adsorb enough moisture to ensure a surface conductivity that is sufficient to prevent accumulation of static electricity. When the humidity falls below about 30 percent, these same materials could become good insulators, in which case accumulation of charge will increase.

6.4.2.2 While humidification does increase the surface conductivity of the material, the charge will only dissipate if there is a conductive path to ground.

6.4.2.3 Humidification is a not a cure-all for all static electricity problems. Some insulators do not adsorb moisture from the air and high humidity will not noticeably decrease their surface resistivity. Examples of such insulators are uncontaminated surfaces of some polymeric materials, such as plastic piping, containers, and films, and the surface of petroleum liquids. These surfaces are capable of accumulating a static electric charge even when the atmosphere has a humidity of 100 percent.

6.4.3 Charge Relaxation and Antistatic Treatments.

6.4.3.1 Based on their properties, liquid and solid materials carrying a static electric charge need time to dissipate, or "relax," this charge. In some cases, the materials can be allowed sufficient time for the charges to relax before being introduced into a hazardous area or process.

6.4.3.2 Charge relaxation can only occur if a path to ground for conduction of the charge is available. Increasing the conductivity of the material will not eliminate hazards if the material remains isolated from ground.

6.4.3.3 A nonconductive material can often be made sufficiently conductive to dissipate static electric charge, either by adding conductive ingredients to its composition or by applying hygroscopic agents to its surface to attract atmospheric moisture. *(See Chapters 7 through 9 for additional information.)*

6.4.3.4 Carbon black can be added to some plastics or rubbers to increase conductivity. Carbon-filled plastics and rubber articles are sometimes sufficiently conductive to be grounded like metal objects. Antistatic additives can also be mixed with liquid and particulate streams to foster charge relaxation.

6.4.3.5 In some cases, particularly with plastic films or sheeting, a material is added to the plastic to attract atmospheric moisture to the surface of the film, thus increasing its surface conductivity. Care should be taken when using antistatic plastic film or sheeting in low humidity situations. In environments with less than 30 percent humidity, film or sheeting can become nonconductive and accumulate static electric charge.

6.4.3.6 Topical hygroscopic coatings will attract atmospheric moisture and make the surface of the coated material conductive. However, these coatings could be easily washed away or rubbed off or could lose effectiveness over time. This type of coating should only be considered a temporary measure to reduce accumulation of static electric charge.

6.4.3.7 Conductive polymers, laminates with conductive elements, and metallized films have been developed for improved static dissipation.

6.5 Charge Neutralization.

6.5.1 General. Air can be made to contain mobile ions that will be attracted to and will eliminate unbalanced static electric charge from surfaces. In the use of air ionizers, one must consider certain factors that can influence their effectiveness, such as environmental conditions (e.g., dust and temperature) and positioning of the device in relation to the material processed, machine parts, and personnel. It is important to note that these control devices do not prevent the generation of static electric charge. They provide ions of opposite polarity to neutralize the generated static electric charge.

6.5.2 Inductive Neutralizers.

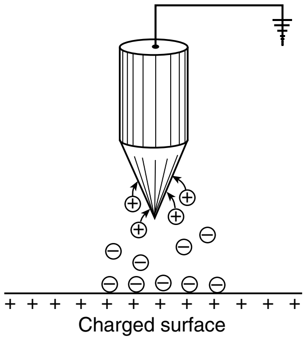
6.5.2.1 Inductive neutralizers include the following:

(1) Needle bars, which are metal bars equipped with a series of needle-like emitters
(2) Metal tubes wrapped with metal tinsel
(3) Conductive string
(4) Brushes made with metal fibers or conductive fibers

Each design is based on or consists of sharply pointed elements arranged for placement in the static electric field near the charged surfaces.

6.5.2.2 A charge drawn from ground to the needle-like tips of an inductive neutralizer produces a concentrated electric field at the tips. If the tips are sharply pointed, the electrical field will be sufficient (i.e., greater than 3 kV/mm) to produce a localized electrical breakdown of the air. This electrical breakdown, known as corona, will inject ions into the air that are free to move to distant charges of opposite polarity. The flow of ions produced in corona constitute a neutralizing current. *(See Figure 6.5.2.2.)*

FIGURE 6.5.2.2 Example of an induction needle.



6.5.2.3 Although inexpensive and easy to install, inductive neutralizers require a minimum potential difference between the object and the needle tip to initiate corona and the neutralizing process. In the absence of this minimum charge, neutralization will not occur, and a residual potential of a few thousand volts will be left on the material when sharp inductive points are approximately within about 12 mm of the surface.

6.5.2.4 It is critically important that inductive neutralizers are connected to a secure ground. If the inductive neutralizer is not grounded, sparks from the induction bar can occur.

6.5.3 Active Electric Static Neutralizers.

6.5.3.1 Electric static neutralizers use a high voltage power supply to produce corona from sharp electrodes. The charge on any object near the device attracts charge from the corona to achieve neutralization. The use of a high voltage power supply eliminates the limitation of inductive neutralizers in control of charges having fields below the corona onset threshold.

6.5.3.2 Electric static neutralizers suitable for hazardous (classified) locations use a high voltage power supply to energize the corona electrodes at 50 Hz to 60 Hz. The use of an alternating field stresses the electrodes to produce both positive and negative ions for use in the neutralizing process. Current from the power supply is capacitive-coupled to each or to several of the sharp electrodes to limit spark energy in the event of a short circuit. These alternating current (AC)–powered static neutralizers must be approved for use in hazardous (classified) locations.

6.5.3.3 Electric static neutralizers that use pulsed or steady-state double-polarity direct current (DC) use a pulsed or steady field to stress the electrodes to produce ions for use in the neutralizing process. The spark energy, in the event of a short circuit, is controlled by current-limiting resistors. Pulsed or double-polarity DC ionizers that are used in hazardous (classified) locations should be listed for such use.

6.5.4 Active Radioactive Static Neutralizers. Radioactive (nuclear) ionizers use ionizing radiation to produce ions for neutralization of static electric charges. The most common radioactive ionizers depend on alpha particle generation from the decay of Polonium-210 (^{210}Po). Performance of radioactive ionizers deteriorates with the decay of the radioactive material. The neutralizers must be registered and installed in accordance with the Nuclear Regulatory Commission regulations and replaced periodically (at least annually) because ionization capability diminishes with radioactive decay. Radioactive ionizers are often used in conjunction with inductive neutralizers to control high charge densities. Although cost and regulatory compliance issues are associated with radioactive ionizers, they are nonincendive, require no wiring, and can reduce static electric charges to the lowest levels.

6.6 Control of Static Charge on Personnel. The human body is an electrical conductor and can accumulate a static charge if insulated from ground. This charge can be generated by contact and separation of footwear with floor coverings, by induction, or by participation in various manufacturing operations. Where ignitible mixtures exist, a potential for ignition from the charged human body exists, and means to prevent accumulation of static electric charge on the human body might be necessary.

6.6.1 Steps to prevent charge accumulation include use of the following:

(1) Conductive flooring and footwear
(2) Personnel grounding devices
(3) Antistatic or conductive clothing

6.6.2 Conductive Flooring and Footwear.

6.6.2.1 Conductive or antistatic flooring can provide effective dissipation of static electricity from personnel. Materials can be solid or they can be coatings that are selected on the basis of wear characteristics, chemical resistance, and the floor area that needs to be covered. Small areas can be handled with a grounded metal plate. Typical resistance to ground for flooring systems should be less than 10^8 ohms. Accumulation of debris, wax, and other high-resistivity materials will compromise the conductivity of the floor.

6.6.2.2* Electrostatic dissipative (ESD) footwear, used in conjunction with conductive flooring, provides a means to control and dissipate static electric charges from the human body. Resistance to earth through ESD footwear and floor should be between 10^6 ohms and 10^9 ohms. For materials with very low ignition energies, the resistance to earth through footwear and flooring should be less than 10^6 ohms. Resistance can be measured with commercially available footwear conductivity testers.

6.6.2.3 Resistance of footwear can increase with accumulation of debris on footwear, use of orthopedic foot beds, and reduced floor contact area. Conductivity of footwear can be tested on a periodic basis to confirm functionality.

6.6.2.4 Conductive footwear is footwear designed to have a resistance to ground through footwear and floor of less than 10^6 ohms and is typically used where materials of low ignition energy, such as explosives and propellants, are handled. Conductive footwear should not be used where a possibility for electrocution by line voltages exists.

6.6.3* Personnel Grounding Devices.

6.6.3.1 Where ESD footwear will not provide adequate personnel grounding, supplementary devices should be used. Such devices include wrist straps, heel/toe grounders, and conductive overshoes. They should be selected so that accumulation of hazardous static electric charge is prevented, while the risk of electrocution is not increased. In most practical situations, grounding of personnel is achieved by ensuring that the resistance from the skin to ground is approximately 10^8 ohms or less. The need to protect against electrocution via a grounding device imposes a minimum resistance from skin to ground of 10^6 ohms. Based on skin contact and contact with the floor, especially during activities where the entire sole of the footwear is not in contact with the floor (e.g., kneeling), effectiveness can be compromised. Grounding devices should have a minimum resistance of 10^6 ohms for shock protection.

6.6.3.2 The simplest type of commercial device is a grounding bracelet with a built-in resistor, typically giving a resistance to ground of about 10^6 ohms for shock protection. Wrist straps of this type have the greatest utility at ventilation hoods and at other locations where limitation on the operator's mobility can be tolerated. Breakaway wrist tether systems could be necessary where emergency egress is needed. A hood can be equipped with two external coiled grounding cords with removable cuff attachments, the latter being kept by individual users.

6.6.3.3 Ground continuity should be checked periodically to the manufacturer's specified limits using a voltmeter or volt ohmmeter or a commercial tester.

6.6.4 Antistatic or Conductive Clothing.

6.6.4.1 Although silk and most synthetic fibers are excellent insulators, and undergarments made from them exhibit static phenomena, no conclusive evidence exists to indicate that wearing such undergarments constitutes a hazard. However, removal of outer garments is particularly hazardous in work areas, such as in hospital operating rooms, explosives manufacturing facilities, and similar occupancies and where clothing is contaminated by flammable liquids. Outer garments used in these areas should be suitable for the work area and should be antistatic. NFPA 99, *Standard for Health Care Facilities*, provides information on test methods for evaluating the antistatic performance of wearing apparel.

6.6.4.2* Although usually a very small likelihood of ignition by a grounded person due to any type of clothing exists, the charging of personnel (which can occur, for example, when personnel are getting out of a forklift truck) is greatly increased by clothing having high resistivity.

6.6.4.3* In oxygen-enriched atmospheres, such as could be present in liquid oxygen filling plants, vapor from the cooled gas can permeate the employee's clothing, rendering it more combustible. A static electric charge that accumulates on the person and then suddenly discharges can ignite the clothing.

6.6.5 Gloves. Gloves should be antistatic or conductive with the same resistivity as prescribed for footwear. Gloves should be tested in conjunction with the footwear.

6.6.6 Cleaning or Wiping Cloths. Synthetic fabrics used in cleaning or wiping cloths can develop sufficient static electric charge to produce discharges capable of igniting solvent vapors. Flammable liquids and combustible liquids used at temperatures above their flash points, where used with synthetic cleaning or wiping cloths, will increase the risk of fire. Typically, charge generation will increase with the speed and vigor of the wiping action. The material being cleaned or wiped, if nonconductive, can also accumulate an incendive charge.

Cotton or synthetic fabric treated with an antistatic compound should be used if static electric charge generation needs to be controlled, especially if cleaning or wiping with flammable solvents. Conductive solvents are recommended. Test methods for determining the electrostatic-generating properties of fabrics can be found in NFPA 99, *Standard for Health Care Facilities.*

6.7 Maintenance and Testing. All provisions for personnel static electricity control should be maintained and tested to remain effective. Preventive maintenance procedures and recommendations can be found in NFPA 99, *Standard for Health Care Facilities*, for clothing, footwear, and flooring.

6.8 Discomfort and Injury. Static shock can result in discomfort and, under some circumstances, injury. While the discharge itself is typically not dangerous to humans, it can cause an involuntary reaction that results in a fall or entanglement with moving machinery. If charge accumulation cannot be avoided and no flammable gases or vapors are present, consideration should be given to the various methods by which contact with metal parts can be eliminated. Such methods include use of nonmetal handrails, insulated doorknobs, and other nonconductive shields.

Chapter 7 Flammable and Combustible Liquids and Their Vapors

7.1 Scope. This chapter discusses the assessment and control of static electricity hazards involved with the storage, handling, and use of flammable and combustible liquids and their vapors and mists. While focused on flammable and combustible liquids, the principles of this chapter also apply to noncombustible liquids and vapors (e.g., wet steam) where their storage, use, and handling can cause a static electricity ignition hazard. The chapter begins with a discussion of the combustion characteristics of liquids and their vapors and mists, followed by a discussion of charge generation and dissipation in liquids. Emphasis is then given to processes involving the following:

(1) Flow in pipe, hose, and tubing
(2) Storage tanks
(3) Process vessels
(4) Gauging and sampling
(5) Tank cleaning
(6) Portable tanks and containers
(7) Vacuum cleaning

7.2 Combustion Characteristics of Liquids, Vapors, and Mists. The following combustion properties of liquids need to be understood in order to properly assess the static electricity ignition hazard:

(1) Flash point
(2) Flammable limit and vapor pressure
(3) Ignition energy
(4) Oxidant concentration

7.2.1* Flash Point. Flash point is the minimum temperature at which a liquid gives off sufficient vapor to form an ignitible mixture with air near the surface of the liquid. Flash point is determined using a variety of test procedures and apparatus, the selection of which sometimes depends on other physical characteristics of the liquid. *(See A.7.2.1 for more detailed information.)*

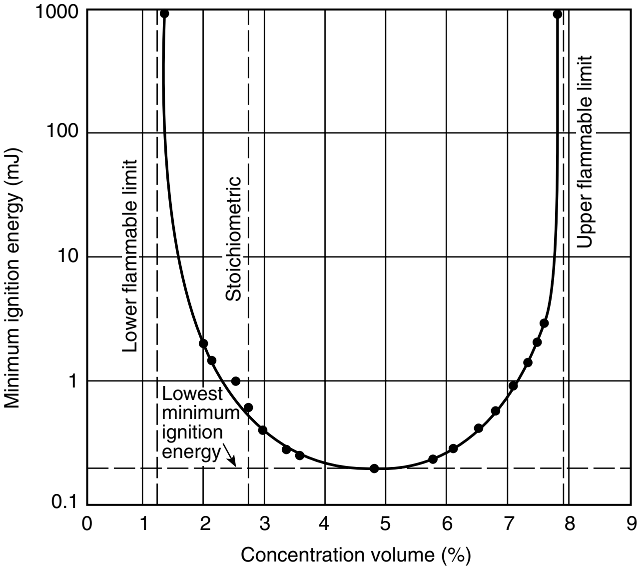
If the flash point of a liquid is at or below typical ambient temperatures, it is likely to evolve an ignitible vapor. The lower the flash point, the higher the vapor pressure and the more likely that a vapor will be present to ignite. Because of the variability in flash point test methods, the published flash point of a particular liquid only approximates the lowest temperature at which ignition is possible for that liquid. Thus, an allowance of 4°C to 9°C below the published flash point should be made when evaluating ignition hazard. The following effects also can generate an ignitible vapor:

(1) Off-gassing of flammable vapors from solids or low-volatility liquids
(2) Processing at pressures below atmospheric pressure
(3) Nonhomogeneity of the vapors above the liquid
(4) Mist, droplets, or foam on the surface of a liquid

7.2.2* Flammable Limits. Vapors or gases in air are flammable only between certain concentrations — the lower flammable limit (LFL) and the upper flammable limit (UFL). The concentrations between these limits constitute the flammable range. Below the LFL, vapors are too lean to burn and above the UFL, they are too rich to burn. Increased pressure (above atmospheric pressure) and increased temperature both widen the flammability range of typical hydrocarbons.

7.2.3 Ignition Energy. The energy needed to ignite a vapor–air mixture varies with the concentration. *(See Figure 7.2.3 for a typical relationship between ignition energy and concentration.)* For most materials, the lowest ignition energy value occurs at a concentration near the midpoint between those for the LFL and UFL. The lowest value is referred to as the minimum ignition energy (MIE). Some MIEs are given in Appendix B.

FIGURE 7.2.3 Minimum ignition energy of benzene as a function of concentration. *(Adapted from Britton, 1992, pp. 56–70.)*

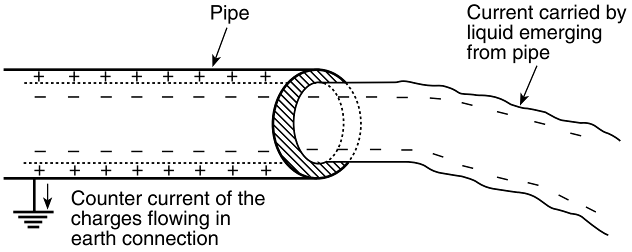


7.2.4* Oxidant Concentration. Combustibility is normally determined for atmospheric air, which contains 21 percent oxygen. With an oxygen-enriched atmosphere, the flammable range expands; that is, the LFL decreases and the UFL increases. If the oxygen concentration is sufficiently reduced by inerting, however, an oxygen concentration below which no ignition is possible is reached. This concentration is referred to as the *limiting oxygen concentration* (LOC). By effectively inerting to below the LOC, the hazard of ignition can be eliminated, as explained in NFPA 69, *Standard on Explosion Prevention Systems.* Other oxidants, if present in the mixture, should be addressed similarly. Laboratory testing might be required to evaluate the hazard.

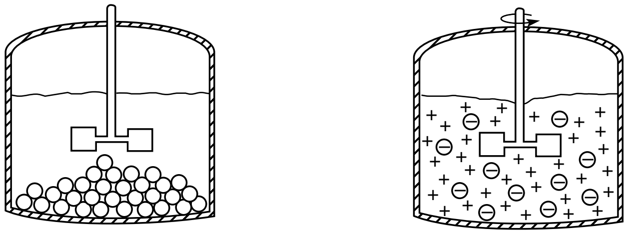
7.3 Generation and Dissipation of Charge in Liquids.

7.3.1* Charge Generation. Charge separation occurs when liquids flow through pipes, hoses, and filters, when splashing occurs during transfer operations, or when liquids are stirred or agitated. The greater the area of the interface between the liquid and surfaces and the higher the flow velocity, the greater the rate of charging. The charges become mixed with the liquid and are carried to receiving vessels where they can accumulate. The charge is often characterized by its bulk charge density and its flow as a streaming current to the vessel. *(See Figure 7.3.1.)*

FIGURE 7.3.1 Examples of charge generation in liquids. *(Walmsley, 1992, p. 33.)*



(a) Flow (pipe charging)



No stirring, no charge

Stirring; charges on liquid and opposite charges on solids but not in equal amounts

(b) Agitation/stirring

7.3.2* Charge Relaxation. Static electric charge on a liquid in a grounded conductive container will dissipate at a rate that depends on the conductivity of the liquid. For liquids with conductivity of 1 picosiemens per meter (1 pS/m) or greater, charge relaxation proceeds by exponential, or ohmic, decay, as described for semiconductive materials in 4.2.4. For liquids with conductivity less than 1 pS/m, relaxation occurs more rapidly than would be predicted by the exponential decay model. *(See 4.2.5.)* According to the Bustin relationship *(see A.7.3.2)*, when low viscosity liquids (less than 30×10^{-6} m^2/sec) are charged, relaxation proceeds by hyperbolic decay. However, for these same liquids, the exponential decay constant gives a conservative estimate for the relaxation time.

7.3.3* Factors Affecting Liquid Charging. In grounded systems, the conductivity of the liquid phase has the most effect on the accumulation of charge in the liquid or on materials suspended in it. A liquid is considered nonconductive (charge accumulating) if its conductivity is below 50 pS/m, assuming a dielectric constant of 2. *(See A.7.3.3 for a detailed discussion of this subject.)* Appendix B lists values of conductivity for typical liquids. What is important is that charge should decay from the liquid fast enough to avoid ignition hazards. The acceptable conductivity in any particular application can be larger or smaller than this range, depending on flow rate and processing conditions.

Conductive liquids, defined as having conductivities greater than 10^4 pS/m, do not pose a hazard due to static electric charge accumulation in typical hydrocarbon and chemical processing and handling operations. Liquids having conductivities of 50 pS/m to 10^4 pS/m are considered semiconductive by this recommended practice.

The charging characteristics of many industrial liquids, particularly non-polar hydrocarbons, are the result of trace contaminants that are present in the liquid, sometimes in concentrations less than 1 part per million (ppm). Thus, industrial liquids can become more or less conductive by orders of magnitude, depending on the concentration of contaminants that result from process, storage, and handling practices.

Conductive liquids that at first could appear to be safe can present a significant hazard if isolated from ground by an insulating container or if suspended in air. When isolated, essentially all charge on the conductive liquid can be released as an incendive spark. When suspended as a mist, significant static electric fields can lead to incendive brush discharge.

7.3.3.1 In the petroleum industry, for tank loading and distribution operations involving petroleum middle distillates, liquids in the semiconductive category are handled as conductive liquids. Such procedures are possible because regulations prohibit use of nonconductive plastic hoses and tanks and multiphase mixtures and end-of-line polishing filters are not involved.

7.3.3.2 In general chemical operations, semiconductive liquids represent a distinct category in which the tendency to accumulate charge varies greatly with the operation and with liquid conductivity. These operations can involve multiphase mixtures, nonconductive tank linings, and microfilters, all of which promote charge accumulation in equipment.

7.4 Flow in Pipe, Hose, and Tubing.

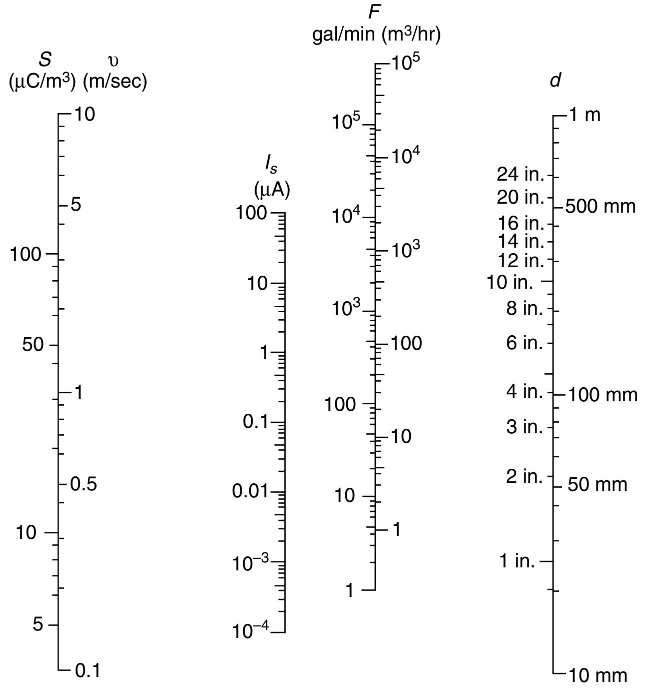
7.4.1* Metal Piping Systems. All parts of continuous all-metal piping systems should have a resistance to ground that does not exceed 10 ohms. A significantly higher resistance could indicate poor electrical contact, although this will depend on the overall system. For flanged couplings, neither paint on the flange faces nor thin plastic coatings used on nuts and bolts will normally prevent bonding across the coupling after proper torque has been applied. Jumper cables and star washers are not usually needed at flanges. Star washers could even interfere with proper torquing. Electrical continuity of the ground path should be confirmed after assembly and periodically thereafter.

Bonding wires might be needed around flexible, swivel, or sliding joints. Tests and experience have shown that resistance in these joints is normally below 10 ohms, which is low enough to prevent accumulation of static charges. However, it is recommended that the manufacturer's specifications be checked or that these joints be inspected, because a few are fabricated with insulating surfaces. When painted, slip flanges (lap joints) using nonconductive gaskets can cause loss of continuity in the grounding path. This loss of continuity can be remedied by using a conductive gasket, such as a flexible, graphite-filled, spiral-wound gasket or by installing a jumper wire across the joint.

It should be ensured that bonding and grounding do not compromise sections of pipe that are supposed to be isolated. For example, insulating flanges could have been installed to avoid arcs from stray current or from cathodic protection systems, which provide a separate ground path.

Figures 7.4.1(a) and (b) provide guidance in estimating the charge on a nonconductive liquid flowing through a smooth pipe.

FIGURE 7.4.1(a) Nomograph for estimating the charge on a nonconductive liquid flowing through a smooth pipe. ***(Pratt, 1997, p. 112.)***



Note: One straight line through the scales simultaneously solves the relations.

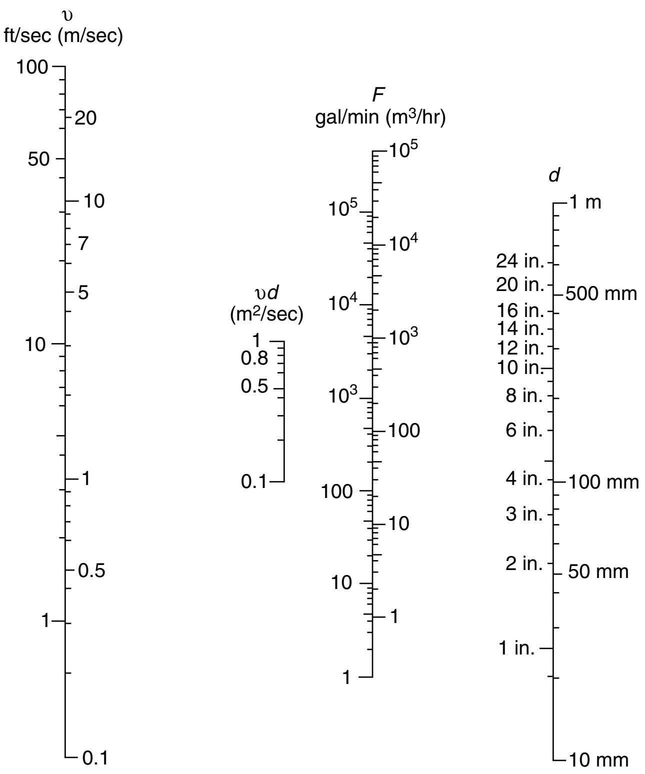
$I_s = 2.5 \times 10^{-5}\, \upsilon^2 d^2$ $S = 3.18 \times 10^{-5}\, \upsilon$ $F = (\pi/4)\, \upsilon d^2$

(To convert from ft/sec to m/sec multiply by 3.28)
(To convert from bbl/hr to m³/hr multiply by 0.159)

7.4.2* Nonconductive Pipe and Lined Pipe. Nonconductive surfaces affect the rates of charge generation and charge dissipation during flow through a pipe. The rate of charge generation is similar in conductive and nonconductive pipes, while the rate of charge loss can be significantly slower in nonconductive pipes. For charged, nonconductive liquids, insulation by the pipe wall can result in charge accumulation of the opposite polarity on the outer surface of the insulating liner or pipe. Charge accumulation can eventually lead to electrical breakdown and pinhole punctures of either the liner or, in the case of nonconductive pipe, the entire wall thickness.

7.4.3* Flexible Hoses and Tubing. Flexible hoses and flexible tubing are available in metal, lined metal, nonconductive plastic, reinforced rubber and plastic, and composite-ply types. Where nonconductive hose or tubing must be used because of process conditions, the hazards of static electric charge generation should be thoroughly investigated. As a minimum, all conductive couplings (e.g., end fittings) and components should be bonded and grounded. If hoses are used immediately downstream of filters in nonconductive liquid service, they should be of metal or other conductive material. Semiconductive liners might be necessary to prevent charge accumulation and pinhole damage to the hose. Conductive hoses should be electrically continuous and the continuity should be periodically checked.

FIGURE 7.4.1(b) Nomograph for estimating fluid flow parameters. ***(Pratt, 1997, p. 114.)***



Note: One straight line through the scales solves the flow relation.

$F = (\pi/4)\, \upsilon d^2$

(To convert from bbl/hr to m³/hr multiply by 0.159)

7.4.4 Fill Pipes. Fill pipes should be conductive and should be bonded to the filling system. Fill pipes should extend to the bottom of the vessel and can be equipped with either a 45 degree cut tip or a tee to divert flow horizontally near the bottom of the vessel being filled. The design should prevent upward spraying during the initial stage of filling. A "slow start" might be necessary so that the inlet velocity is held to less than 1 m/sec until the outlet of the dip pipe is covered by at least two pipe diameters of liquid.

7.4.5 Filtration.

7.4.5.1 Microfilters. Microfilters typically have pore sizes less than 150 μm. These filters generate very large streaming currents with nonconductive liquids, due to their large contact area. (Conductive liquids typically dissipate their charge to ground through the body of the liquid.) Streaming currents will frequently be greater than those for the pipe flow entering the microfilter by two orders of magnitude and the charge density added to the liquid can exceed 2000 μC/m³.

To prevent these charges from entering the receiving vessel, the filter should be placed far enough upstream so that the charge can decay to the same magnitude as it would be in the pipe flow. Common industry practice is to provide 30 seconds of residence time in the pipe or conductive hose downstream of the microfilter, especially if the conductivity of the liquid is not known. For nonconductive liquids that have both very low conductivity (i.e., less than 2 pS/m) and high viscosity (i.e., greater than 30 centistokes) at the lowest intended operating temperature, longer residence times might be appropriate. In these cases, a residence time of up to three times the relaxation time constant of the liquid should be considered.

7.4.5.2 Strainers. Mesh strainers finer than 150 μm should be treated as microfilters. Mesh strainers coarser than 150 μm can also generate significant static electric charge when fouled with accumulated debris. If such coarse strainers are used in services where debris can be expected to accumulate, then these strainers should also be treated as microfilters.

7.4.5.3 Polishing Filters. A polishing filter is sometimes placed at the end of a delivery line to remove debris. This filter might be a bag installed on the end of a hose and directly exposed to the vapor in the tank. Filters used in flammable liquid service should be enclosed in grounded metal housings.

7.4.6 Suspended Material. Immiscible and marginally soluble liquids and slow-dissolving solids can disperse as droplets or as an emulsion. *(For a discussion of examples of such situations in mixing operations, see 7.10.1.)* Where a nonconductive liquid contains a dispersed phase, such as water in oil, the continuous phase determines the charge relaxation behavior. Charge generation is typically greater for such suspensions than that for a single phase.

7.4.7 Miscellaneous Line Restrictions. Piping system components such as orifice plates, valves, elbows, and tees increase turbulence and can increase the rate of charge generation. Brief contact with a plastic component, in particular, can cause significant charge generation. Suspended material such as water *(see 7.4.6)* has also been found to increase this effect.

7.5 Storage Tanks.

7.5.1 General. Liquid flowing into a tank can carry a static electric charge that will accumulate in the tank. This charge can be detected as a potential above the surface of the liquid in the tank. The maximum surface potential attained depends not only on the charge density of the incoming liquid but also on the dimensions of the tank. For commercial tanks of equal volume, the maximum potential will be greater in tanks having smaller cross-sectional areas, because liquid depth increases faster relative to the rate of charge relaxation. Smaller potentials will therefore be generated in, for example, a near-rectangular barge tank than in a cylindrical vertical tank of the same volume.

7.5.2 Conductive Fixed-Roof Storage Tanks. Charge accumulation in the liquid in a tank can lead to static electric discharge between the liquid surface and the tank shell, roof supports, or tank appurtenances. The charge generation rate is influenced by turbulence in the liquid and by the settling of particulate matter, such as water droplets, iron scale, and sediment.

7.5.2.1 Precautions. If the vapor space in the tank is likely to contain an ignitible mixture (e.g., in cases where intermediate vapor pressure products or low vapor pressure products contaminated with high vapor pressure liquids are stored), or where switch loading is practiced, the following protective measures should be taken:

(a) Splash filling and upward spraying should be avoided. The fill pipe should discharge near the bottom of the tank, with minimum agitation of water and sediment on the tank bottom.

(b) If possible, the inlet flow velocity should be limited during the initial stage of tank filling to reduce agitation and turbulence. The flow velocity of the incoming liquid should be no greater than 1 m/sec until the fill pipe is submerged either two pipe diameters or 0.6 m, whichever is less. Since too low a velocity can result in settling out of water at low points in the piping, the inlet flow velocity should be kept as close to 1 m/sec as possible during this period. Otherwise, subsequent re-entrainment of water or other contaminants when the velocity is increased could significantly increase the product's charging tendency.

(c)*For storage tanks greater than 50 m^3 containing liquids that are either nonconductive or whose conductivity is unknown, the inlet flow velocity can be increased to 7 m/sec after the fill pipe is submerged. Where operating experience, such as in the petroleum industry, has shown that the practice is acceptable, the inlet flow velocity can be increased above 7 m/sec, but in no case greater than 10 m/sec. See Figures 7.4.1(a) and (b) for determining flowrate.

(d) If the liquid is nonconductive and contains a dispersed phase, such as entrained water droplets, the inlet flow velocity should be restricted to 1 m/sec throughout the filling operation.

(e) A 30-second minimum residence time should be provided for liquid to flow between upstream microfilter screens and the tank *(see 7.4.5)*.

(f) Tanks should be inspected for ungrounded conductive objects, such as loose gauge floats and sample cans. If these objects are floating on the liquid surface, they can promote sparks.

(g) Lines should not be blown out with air or other gases if the liquid is a Class I liquid or is handled at or above its flash point. Introducing substantial amounts of air or other gas into a tank through the liquid can create a hazard due to charge generation, misting of the liquid, and formation of an ignitible atmosphere.

7.5.2.2 Grounding. Storage tanks for nonconductive liquids should be grounded. Storage tanks on grade-level foundations are considered inherently grounded, regardless of the type of foundation (e.g., concrete, sand, or asphalt). For tanks on elevated foundations or supports, the resistance to ground can be as high as 10^6 ohms and still be considered adequately grounded for purposes of dissipation of static electric charges, but the resistance should be verified. The addition of grounding rods and similar grounding systems will not reduce the hazard associated with static electric charges in the liquid.

7.5.2.3 Spark Promoters. A tank gauging rod, high-level sensor, or other conductive device that projects downward into the vapor space of a tank can provide a location for static electric discharge between itself and the rising liquid. These devices should be bonded securely and directly downward to the bottom of the tank by a conductive cable or rod to eliminate a spark gap or should be installed in a gauging well that is bonded to the tank. They should be inspected periodically to ensure that the bonding system has not become detached. If tank fixtures are nonconductive, the potential for sparking does not exist and no specific measures are needed. Devices that are mounted to the sidewall of the tank (e.g., level switches or temperature probes) and project a short distance into the tank might not pose a static electric discharge hazard. These situations should be evaluated on an individual basis.

7.5.2.4 Tank Mixers. In-tank jet mixing or high-velocity agitator mixing can stir up water and debris and cause splashing at the surface that can generate static electric charges. If an ignitible mixture exists at the surface, ignition is possible. Surface splashing should be minimized. Gas blanketing or inerting can be employed to eliminate the ignition hazard.

7.5.2.5 Gas Agitation. Gas agitation using air, steam, or other gases is not recommended because it can produce high levels of charge in liquids, mists, or foams. In addition, air agitation can create an ignitible atmosphere in the vapor space of the tank. If gas agitation is unavoidable, the vapor space should be purged prior to mixing and the process should be started slowly to ensure that static electric charge does not accumulate faster than it can dissipate. Note that special precautions need to be taken to prevent agitation with air to dilute any initial inerting. Similarly, while agitation with an inert gas can eventually result in an inert vapor space, the electrostatic charge buildup due to the agitation process can result in a spark and ignition before inerting of the tank vapor space is achieved. A waiting time should be observed prior to any gauging or sampling activities.

7.5.3 Conductive Floating Roof Storage Tanks. Floating roof storage tanks are inherently safe, provided the floating roof is bonded to the tank shell. Bonding is typically achieved by providing shunts between the floating roof or cover and the wall of the tank. The shunts are installed for lightning protection, but they also provide protection from static electric charges that could be generated. If the floating roof is landed on its supports, charge accumulation in the surface of the liquid can occur, and the same precautions as for a fixed roof tank should be followed. If an internal floating roof tank is not adequately ventilated, flammable vapor can accumulate between the floating roof and the fixed roof.

7.5.4 Coated and Lined Tanks. Metal tanks with nonconductive coatings or linings can be treated as a conductive tank if either of the following criteria apply:

(a) The nonconductive coating or lining has a volume resistivity equal to or lower than 10^{10} ohm-m, such as fiberglass-reinforced linings for corrosion prevention, and is no thicker than 2 mm.

(b) The nonconductive lining has a volume resistivity greater than 10^{10} ohm-m, such as polyethylene or rubber linings, but has a breakdown potential less than 4 kV.

Metal tanks with nonconductive coatings or linings that do not meet the criteria of 7.5.4(a) or (b) should be treated as nonconductive tanks. Regardless of the coating or lining thickness or resistivity, the tank should be bonded to the filling system. The coating or lining is not regarded as a barrier to the flow of static electric charges. Its resistivity is of the same order of magnitude as that of the liquid or there could be small bare areas (holidays) in the coating.

A thin coat of paint, a thin plastic liner, or a layer of metal oxide on the inside of piping, vessels, or equipment does not constitute a static electric hazard.

7.5.5 Tanks Constructed of Nonconductive Materials. Tanks constructed of nonconductive materials are not allowed for storing Classes I, II, and IIIA liquids except under special circumstances, as outlined in Section 2.2 of NFPA 30, *Flammable and Combustible Liquids Code. (See 7.10.7 for design and use recommendations.)*

7.6 Loading of Tank Vehicles. Recommended loading precautions for tank vehicles vary with the characteristics of the liquid being handled and the design of the loading facility. A summary of precautions recommended when a flammable mixture exists in the tank vehicle compartment, based on API RP 2003, *Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents,* is provided in Table 7.6. These precautions are intended for tank vehicles with conductive (metal) compartments. *(For compartments with nonconductive linings, see 7.10.4. For compartments of nonconductive material, see 7.10.7.)*

7.6.1 Top Filling. Splash filling should be avoided by using a fill pipe that is designed according to the recommendations in 7.4.4.

7.6.2 Bottom Filling. The bottom-filling inlet should be designed with a deflector or a diverter to prevent upward spraying and generation of mist. Using a cap or a tee to direct incoming liquid sideways toward the compartment walls, rather than upward, will achieve this objective.

7.6.3 Switch Loading. The practice of loading a high flash point, low conductivity liquid into a tank that previously contained a low flash point liquid is known as switch loading. This practice can result in the ignition of residual flammable vapor as the tank is filled. The methods of hazard prevention are similar to those for 7.5.2.1(a), (b), (d), (e), (f), and (g). Flow velocities are found in Table 7.6.

7.6.4 Highway Transport. As noted in API RP 2003, *Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents,* tank vehicles normally create no static electricity hazard during transport, provided they are compartmented or contain baffles. The compartments or baffles minimize sloshing of the liquid in the tank vehicle, which could result in significant charge generation. Clear bore (unbaffled) tank vehicles should not be used for liquids that can generate an ignitible mixture in the vapor space.

7.6.5 Antistatic Additives. Charge accumulation can be reduced by increasing the conductivity of the liquid by adding a conductivity-enhancing agent (antistatic additive). These additives are normally added in parts per million concentrations and should be used in accordance with manufacturer instructions. When antistatic additives are used as a primary means of minimizing accumulation of static electric charge, the operator should verify the concentration of the additive at critical points in the system.

7.7* Vacuum Trucks. For control of static electricity, hoses should be conductive or semiconductive. Alternatively, all conductive components should be bonded and the truck should be grounded. In no case should plastic dip pipes or plastic intermediate collection pans or drums be used.

7.8 Railroad Tank Cars. In general, the precautions for railroad tank cars are similar to those for tank vehicles in Section 7.6. The major exception is the larger volume typical of railroad tank cars (e.g., greater than 87 m^3) compared with that of tank vehicles (e.g., about 50 m^3). This greater volume allows greater maximum filling rates to be used, up to a maximum of $(0.8/d)$ m/sec, where d is the inside diameter of the inlet, in meters. Many tank cars are equipped with nonconductive bearings and nonconductive wear pads located between the car itself and the trucks (wheel assemblies). Consequently, resistance to ground through the rails might not be low enough to prevent accumulation of a static electric charge on the tank car body. Therefore, bonding of the tank car body to the fill system piping is necessary to protect against charge accumulation. In addition, because of the possibility of stray currents, loading lines should be bonded to the rails.

Table 7.6 Summary of Precautions for Loading Tank Vehicles

	Liquid Being Loaded			
	Nonconductive			
Recommended Loading Precaution[1]	Low Vapor Pressure	Intermediate Vapor Pressure	High Vapor Pressure[6]	Conductive[3,4]
1. BONDING AND GROUNDING. Tank trucks should be bonded to the fill system, and all bonding and grounding should be in place prior to starting operations. Ground indicators, often interlocked with the filling system, are frequently used to ensure bonding is in place. Bonding components, such as clips, and the fill system continuity should be periodically examined and verified. For top loading, the fill pipe should form a continuous conductive path and should be in contact with the bottom of the tank.	Yes[2]	Yes	Yes	Optional
2. INITIAL LOADING. Top loading fill pipes and bottom loading systems should be equipped with spray deflectors and splash filling should be avoided. A slow start (i.e., velocity less than 1 m/sec) should be employed until the inlet into the compartment is covered by a depth equal to two fill line diameters to prevent spraying and to minimize surface turbulence.	Yes	Yes	Yes	Yes
3. MAXIMUM LOADING RATE. The maximum loading rate should be limited so the velocity in the fill pipe or load connection does not exceed 7 m/sec or $(0.5/d)$ m/sec (where d = inlet inside diameter in meters), whichever is less.[5] Transition from slow start to normal pumping rate can be achieved automatically using a special loading regulator tip (which shifts rate when submerged to a safe depth). Excessive flow rates should be avoided either procedurally or by system design, which is the recommended method.	Yes[2]	Yes	Optional[3]	Optional
4. CHARGE RELAXATION. A residence time of at least 30 seconds should be provided between any microfilter or strainer and the tank truck inlet.[7] A waiting period of at least 1 minute should be allowed before the loaded tank compartment is gauged or sampled through the dome or hatch. However, sampling and gauging via a sample well (gauge well) can be done at any time.	Yes[2]	Yes	Yes	Optional
5. SPARK PROMOTERS. A tank gauging rod, high-level sensor, or other conductive device that projects downward into the vapor space of a tank can provide a location for static discharge between itself and the rising liquid and should be avoided. These devices should be bonded securely and directly downward to the bottom of the tank by a conductive cable or rod (to eliminate a spark gap), or should be installed in a gauging well that is bonded to the bottom.[8] Periodic inspection should be conducted to ensure that the bonding system does not become detached and that there are no ungrounded components or foreign objects.	Yes	Yes	Yes	Optional

[1] The recommended loading precautions vary with the product being handled. In loading operations where a large variety of products are handled and where it is difficult to control loading procedures, such as at self-service loading racks, following a single, standard procedure that includes all of the precautions is recommended.

[2] Recommended loading precautions need not be applied if only low vapor pressure combustible liquids at ambient temperatures are handled at the loading rack and there is no possibility of switch loading or cross contamination of products. All loading precautions should be followed when handling low vapor pressure products at temperatures near (within 4°C to 9°C) or above their flash point.

[3] When additives are used to increase conductivity, caution should be exercised. *(See 7.6.5.)*

[4] Semiconductive liquids can accumulate charge where charging rates are extremely high or where they are effectively isolated from ground. They could need to be handled as nonconductive. *(See 7.3.3.1 and 7.3.3.2.)*

[5] When the product being handled is a nonconductive, single-component liquid (such as toluene or heptane), the recommended maximum fill rate is $(0.38/d)$ m/sec.

[6] If high vapor pressure products are handled at low temperatures (near or slightly below their flash point), all of the recommended loading precautions should be followed.

[7] Very low conductivity and high viscosity products can require additional residence time of up to 100 seconds. *(See 7.4.5.1.)*

[8] If these devices are nonconductive, the potential for sparking does not exist and no specific measures need be taken. Devices that are mounted to the sidewall of the tank (e.g., level switches and temperature probes), that project a short distance into the tank, and that have no downward projection might not pose an electrostatic hazard. These situations should be evaluated on an individual basis.

7.9 Marine Vessel and Barge Cargo Tanks. Marine vessel and barge cargo tanks are beyond the scope of this recommended practice. The recommendations given in the *International Safety Guide for Oil Tankers and Terminals* (ISGOTT) should be followed.

7.10 Process Vessels.

7.10.1 Means of Static Electric Charge Accumulation. Accumulation of static electricity in process vessels occurs by the same methods as described in Section 7.5 for tanks. Where a conductive and a nonconductive liquid are to be blended, the conductive liquid should be added to the vessel first, if possible, so that the conductivity of the mixture is as high as possible throughout the mixing process. Re-entry of recirculation loops should be designed to minimize splashing and surface disruption, for example, by use of subsurface jets that do not break the liquid's surface.

7.10.2* Procedures for Transfer to Tanks. When introducing two or more nonconductive liquids to a blending tank, the less dense liquid should be loaded first to avoid a surface layer comprising the lighter, more highly charged component. Splash recirculation should normally be done only if the vessel is inerted or vapor enriched.

7.10.3 Agitation. Agitators should be covered with sufficient depth of liquid before being operated, to minimize splashing, or should be operated at reduced speed until sufficient depth has been achieved. In cases where hazardous charge accumulation cannot be avoided using the measures discussed in this section, the vessel can be inerted.

7.10.4 Vessels with Nonconductive Linings. The accumulation of static electric charge can result in pinhole damage to equipment such as enamel- or glass-lined reactors. Since static electric discharges often occur at the liquid interface as liquid drains from the wetted wall, a vapor ignition hazard could also exist. In some cases, it is possible to specify static dissipative coatings for the vessel or agitator. It is recommended that conductive vessels and appurtenances be bonded and grounded. In some cases, inerting might be necessary.

7.10.5 Adding Solids. The most frequent cause of static electric ignitions in process vessels is the addition of solids to flammable liquids in the vessels. Even when the vessel is inerted, large additions of solids will introduce air into the vessel while expelling flammable vapor from the vessel. The sudden addition of a large volume of solids can also result in static discharge from a floating pile of charged powder. It is recommended that manual addition of solids through an open port or manway be done only in 25-kg batches. Larger batch additions [e.g., from flexible intermediate bulk containers *(see 9.1.7)*] should be done through an intermediate hopper with a rotary valve or an equivalent arrangement. The hopper can be separately inerted to reduce air entrainment into the mixing vessel while expulsion of vapor into the operating area can be avoided by venting the vessel to a safe location. The addition of solids from nonconductive plastic bags can be hazardous even if the solids are noncombustible (e.g., silica). Bags should be constructed of paper, plies of paper and plastic in which the nonconductive plastic film is covered by paper on both sides, or antistatic plastic. Because grounding clips can be impractical, such bags can be effectively grounded by contact with a grounded conductive vessel or skin contact with a grounded operator. Fiber drums or packages should not have a loose plastic liner that can leave the package and behave like a plastic bag. Metal chimes should be grounded. Personnel in the vicinity of openings of vessels that contain flammable liquids should be grounded and special attention should be paid to housekeeping, because accumulation of nonconductive residues (e.g., resins) on the floor or on items such as grounding clips can impair electrical continuity.

7.10.6 Agitation. When solids are dissolved or dispersed into nonconductive liquids, the rate of charge generation can be large depending on factors such as solids loading, particle size, and agitation rate. Dissipation of the charge is frequently achieved by raising the conductivity of the continuous phase by reformulation with conductive solvents or by the addition of antistatic additives. Ignition hazards can alternatively be controlled by inerting.

7.10.7 Nonconductive Process Vessels. In general, nonconductive process vessels should not be used with flammable liquids. They present external ignition risks if their outer surfaces become charged. If a nonconductive tank is to be used and the possibility exists that the atmosphere around the tank or in the vapor space could be ignitible, the following should be incorporated to ensure the safe dissipation of charge and to prevent discharges:

(a) All conductive components (e.g., a metal rim and hatch cover) should be bonded together and grounded.

(b) Where used to store nonconductive liquids, an enclosing, grounded conductive shield should be provided to prevent external discharges. This shield can be in the form of a wire mesh buried in the tank wall, provided it is grounded. The shield should enclose all external surfaces.

(c) Where used to store nonconductive liquids, the tank should have a metal plate with a surface area not less than 0.05 cm^2/m^3 of tank volume located at the bottom of the tank and bonded to ground. This plate provides an electrical path between the liquid contents and ground through which the charge can dissipate.

(d) Where used to store conductive liquids, a grounded fill line extending to the bottom of the tank or an internal grounding cable extending from the top to the bottom of the tank and connected to ground should be provided. A grounded fill line that enters at the bottom and does not introduce a spark promoter fulfills this recommendation.

7.11 Gauging and Sampling. Gauging and sampling operations, including temperature measurement, can introduce spark promoters into a storage tank or compartment. It is recommended that a conductive gauging well for manual sampling and gauging be used. The precautions given in Section 7.11 should be taken where use of a gauging well is not possible, where the material stored is a nonconductor, or where the vapor space of the container could be ignitible. Where these operations are conducted manually, the personnel grounding recommendations of Section 6.6 should be considered.

7.11.1 Materials. Gauging and sampling systems should be either completely conductive or completely nonconductive. For example, conductive sampling and gauging devices should be used with a conductive lowering device, such as a steel tape or cable. Chains are not electrically continuous and should not be used in flammable atmospheres. Conductive sampling and gauging devices, including the sampling container and lowering device, should be properly bonded to the tank or compartment. Such bonding should be accomplished by use of a bonding cable or by maintaining continuous metal-to-metal contact between the lowering device and the tank hatch.

Ideally, if nonconductive hand gauging or sampling devices are used, no waiting period is required after loading or filling. However, it should be noted that these devices might not retain the necessary level of nonconductivity due to environmental factors such as moisture or contamination. Therefore, an appropriate waiting period is also recommended when nonconductive devices are used.

Cord made from synthetic material such as nylon should not be used due to possible charging if it slips rapidly through gloved hands. Although natural cellulosic fiber cord can, in principle, be used, it is found that such cord is frequently composed of a natural synthetic blend, with corresponding charge generating ability.

7.11.2 Gauging. Where possible, gauging should be carried out with automatic gauging systems. These can be used safely in tanks, provided the gauge floats and similar devices are electrically bonded to the tank shell through a conductive lead-in tape or conductive guide wires. Free-floating, unbonded floats can be effective spark promoters and should be avoided. Noncontact gauging devices, such as radar and ultrasonic gauges, are also satisfactory, provided electrical continuity is ensured. Isolated conductive components must be avoided.

7.11.3 Waiting Period. Depending on the size of the compartment and the conductivity of the product being loaded, a sufficient waiting period should be allowed for accumulated charge to dissipate. A 30-minute waiting period is recommended before gauging or sampling storage tanks greater than 40 m^3, unless a gauging well is used. The waiting period before gauging or sampling of smaller vessels can be reduced to 5 minutes for tanks between 20 m^3 and 40 m^3 and to 1 minute for tanks less than 20 m^3. Longer waiting periods might be appropriate for very low conductivity liquids ($\kappa < 2$ pS/m) or nonconductive liquids that contain a second dispersed phase (such as a Class I liquid with more than 0.5 weight percent water). If a gauging well is used, a waiting period is unnecessary.

7.12 Tank Cleaning.

7.12.1 Water Washing. The mist created in a tank by water spraying can be highly charged. This is a particular problem with tanks larger than 100 m^3, due to the size of the mist cloud that can form. Water washing using sprays should only be done in an inerted or nonflammable atmosphere. Although specifically written for marine cargo tanks, the *International Safety Guide for Oil Tankers and Terminals* presents a comprehensive discussion of tank cleaning. Tanks of less than 100 m^3 and with all conductive components grounded have a negligible discharge hazard. Where a possibility of steam entering the tank during the water-washing process exists, the precautions in 7.12.3 should be followed.

7.12.2 Solvent Washing. Mist charge densities created by flammable solvents are similar to those from water washing and similar precautions should be taken regarding grounding of conductive components. Where an ignitible atmosphere or mist cannot be avoided because of the type of solvent or cleaning process used, the tank or vessel being cleaned should be inerted or enriched to reduce the likelihood of ignition during the cleaning process. Where the vessel is not inerted (or enriched) and an ignitible atmosphere is present, the following precautions should be considered when using solvent as a cleaning agent:

(a) The solvent should be conductive. When a solvent blend such as reclaimed solvent is used, the conductivity should be checked periodically.

(b) High flash point materials (at least 9°C above the maximum operating temperature during cleaning) should be used. The flash point should be confirmed on a daily basis.

(c) The cleaning system should be conductive and bonded to the tank. Continuity tests of all bonded equipment should be done periodically.

(d) Ungrounded conductive objects should not be introduced into the tank during the cleaning process or for a sufficient period of time after the cleaning process. This waiting period might have to be several hours, due to generation of mist.

7.12.3 Steam Cleaning. Steam cleaning can create very large charge densities with correspondingly large space charge potentials that increase with the size of the tank. Therefore, the following precautions are recommended:

(1) Tanks larger than 4 m^3 should be inerted before steam cleaning.
(2) All components of the steaming system should be conductive and grounded.
(3) All conductive components of the tank should be bonded and grounded.

7.12.4 Internal Grit Blasting. Where possible, tanks and process vessels should be clean and free of ignitible materials (no more than 10 percent of LFL). Hose used for grit blasting should be grounded and the resistance to ground from any part of the hose assembly, especially the nozzle, should not exceed 10^6 ohms. *(See A.7.4.3.)*

7.13 Portable Tanks, Intermediate Bulk Containers (IBCs), and Containers. The following practices are recommended to reduce static electricity hazards during filling and emptying of portable tanks, IBCs, and containers.

7.13.1 Metal Portable Tanks and IBCs. Metal portable tanks and IBCs should be bottom-filled, if possible. Where used for nonconductive flammable liquids, filters should be placed at least 30 seconds upstream, as recommended in 7.4.5. The portable tank or IBC should be bonded to the fill system prior to opening and should be closed before being disconnected from the bond. Filling rates should be similar to those normally used for drum filling, about 225 L/min or less, unless the container is inerted. If the fill pipe does not extend close to the bottom and the vessel is not inerted, a slow start velocity of 1 m/sec or less should be used until the fill pipe is submerged to about 150 mm. Portable tanks and IBCs with nonconductive linings present hazards somewhat more severe than with drums, due to the larger capacity and the greater energy that can be stored for equal charge densities.

7.13.2 Nonconductive Portable Tanks and IBCs. Filling a nonconductive portable tank or IBC with combustible liquids at temperatures below their flash points presents no significant static electric ignition hazard. Filling such a vessel with a combustible liquid above or within 9°C of its flash point should be done as if the liquid were flammable. Refilling a vessel that could contain flammable vapors from a previous product should not be allowed. Additionally, the routine handling of nonconductive vessels filled with any type of liquid can generate a charge on the outside surface of the vessel. Nonconductive portable tanks and IBCs should not be used where ignitible ambient vapors are present.

Portable tanks and IBCs constructed of nonconductive materials are prohibited for use with Class I liquids by NFPA 30, *Flammable and Combustible Liquids Code.* Where such containers are used for Class II and Class III liquids, the precautions for filling depend on the size of the container, the container design, and the conductivity of the liquid.

7.13.3 Metal Containers. When being filled, metal containers and associated fill equipment should be bonded together and grounded. Bonding should be done with a clamp having hardened steel points that will penetrate paint, corrosion products, and accumulated material using either screw force or a strong spring. *(See Appendix C for recommendations.)* The clamp should be applied prior to removing the container bungs and at a point on the top chime that is located away from the bung openings. The grounded fill pipe should be cut at approximately 45 degrees and be left relatively sharp to inhibit brush discharges from the liquid surface. The tip of the fill pipe should extend to within 25 mm of the bottom of the drum and remain beneath the liquid surface until the drum is filled. Viscous liquids that flow without splashing can be deflected by a short fill nozzle to flow down the inside wall of the drum. Inerting of the drum is seldom necessary.

When dispensing from a metal container, it should be grounded. Self-closing, metal dispensing valves should be used. When dispensing from an upright drum, the dip pipe, conductive hose, and pump should be bonded to the drum and grounded. *(For funnels and receiving containers, see 7.13.6.)*

7.13.4 Plastic-Lined Metal Containers. The effects of static electricity from thin, internal coatings such as phenolic or epoxy paints can be neglected, provided the lining is not thicker than 2 mm. A container with a thin lining up to 2 mm in thickness can be treated as a metal container. Where the drum has a lining of nonconductive plastic thicker than 2 mm, it should be treated as a nonconductive container, unless it can be shown that the surface resistivity is not greater than 10^{10} ohms per square.

7.13.5 Plastic Containers. The use of plastic containers for Class I liquids is limited by NFPA 30, *Flammable and Combustible Liquids Code.* Where such containers are used for Class II and Class III liquids, the precautions for filling depend on the size of the container, the container design, and the conductivity of the liquid. Since plastic containers cannot be grounded, they should not be used for Class I liquids or handled in flammable atmospheres without expert review of the hazards. For Class II liquids, hazards of static electricity should be addressed as follows:

(1) Where the liquid might exceed its flash point during filling or emptying
(2) Where the container might be stored or handled in an ignitible ambient atmosphere

In 7.13.5(1), options include bottom filling and cooling of the liquid prior to unloading, especially if the container has been in direct sunlight or in a hot storage area. Continuous inerting during unloading can also be considered.

In 7.13.5(2), plastic containers should be stored away from containers of flammable liquids, so that the hazard of static electric discharge from the external surface of the plastic container is avoided.

7.13.6 Hand-Held Containers Not Greater than 20 L Capacity. The fire risk from static electricity increases with the volume of the container and the volatility of liquid handled. Thus, the smallest volume container capable of effectively fulfilling a particular need should normally be selected and should not exceed 20 L. Listed safety cans are recommended, especially those types equipped with a flexible metal dispensing hose so they can be used without a funnel. Because nonconductive containers cannot be grounded, they should be limited to 2 L for Class IA liquids and 5 L for Class IB and Class IC liquids. An exception is gasoline, where approved 20 L plastic cans have been widely used for many years with no reported increase in ignition incidents due to static electricity compared to metal cans. This is in part due to the rapid establishment of rich (above the UFL) gasoline vapor inside the can; these plastic containers should not be used for other flammable liquids without review of the hazards. Unlike gasoline, conductive liquids such as alcohols can become inductively charged by a charged plastic container and give rise to sparks. In addition, the container can contain an ignitible atmosphere.

7.13.6.1 Nonconductive Containers. Subject to the volume limitations described in 7.13.6, it is common to handle flammable liquids in small glass or plastic containers of 0.5 L capacity or less. Where such containers are involved in frequent transfer operations, such as a small-scale solvent blending operation, a grounded metal funnel whose spout extends to the bottom of the container should be used when filling the container. This practice ensures that any charge induced on the liquid by the container, as could happen if the plastic container has been charged by rubbing, is dissipated through the grounded funnel. Plastic or glass funnels should be used only where essential for compatibility reasons.

7.13.6.2 Containers for Sampling. Ignition risk is greatly increased when an ignitible atmosphere is present outside the container; for example, when sampling directly from a tank or transferring a sample near a manway, since this can precipitate a large fire or explosion. A grounded metal sample "thief" or glass bottle in a grounded metal sample cage can be used in such cases. Nonconductive plastic containers should be avoided, except when used in well-ventilated areas, since they are more easily charged than glass. If outdoor sampling is carried out at sample spigots that are located away from tank openings and in freely ventilated areas, and sampled quantities are 1 L or less, the fire risk is, in most cases, insufficient to require any special procedures other than bonding of metal components.

7.13.7* Cleaning. Containers should be bonded and grounded prior to opening for cleaning operations such as steaming. Cleaning equipment should also be bonded or grounded.

7.14* Vacuum Cleaners. Collecting liquids and solids in an ignitible atmosphere using a vacuum cleaner can create a significant hazard due to ignition from static electric discharge. If it is necessary to use such equipment in a process area, the hazards and the procedures for safe use should be carefully reviewed and clearly communicated to the potential users.

7.15 Clean Gas Flows. Usually a negligible generation of static electricity occurs in single-phase gas flow. The presence of solids such as pipe scale or suspended liquids such as water or condensate will create charge, which is carried by the gas phase. The impact of the charged stream on ungrounded objects can then create spark hazards. For example, carbon dioxide will form charged solid "snow" when discharged under pressure. This phenomenon can create an ignition hazard in an ignitible atmosphere. For this reason, carbon dioxide from high-pressure cylinders or fire extinguishers should never be used to inert a container or vessel. Gases with very low ignition energies, such as acetylene and hydrogen, that contain suspended material can be ignited by corona discharge when escaping from stacks at high velocity. This phenomenon is associated with electrical breakdown at the periphery of the charged stream being vented. Such discharges can occur even if the equipment is properly grounded.

7.16 Plastic Sheets and Wraps. Nonconductive plastic sheets and wraps, such as those used to wrap shipping pallets, present hazards similar to those of plastic bags. Such sheets and wraps can generate brush discharges from their surfaces following rubbing or separation of surfaces. Isolated wet patches can also create spark hazards. An additional problem is charging of personnel during handling. It is recommended that plastic sheet and wrap not be brought into areas that can contain ignitible atmospheres. Plastic pallet wrap can be removed outside the area and, if necessary, can be replaced by a suitable tarpaulin or other temporary cover. Antistatic wrap is available. Tear sheets (used outside many clean areas) can generate significant static electric charge when pulled from a dispenser, and precautions are similar to those for plastic sheet. *(Additional information on handling sheet materials is found in Section 9.2.)*

Chapter 8 Powders and Dusts

8.1 General. Powders include pellets, granules, and dust particles. Pellets have diameters greater than 2 mm, granules have diameters between 0.42 mm and 2 mm, and dusts have diameters of 420 micrometers (microns, µm) or less. It should be noted that aggregates of pellets and granules will often also contain a significant amount of dust. The movement of powders in industrial operations will commonly generate static electric charges. The accumulation of these charges and their subsequent discharge can lead to fires and explosions.

8.2 Combustibility of Dust Clouds.

8.2.1 A combustible dust is defined as any finely divided solid material 420 µm or smaller in diameter (i.e., material that will pass through a U.S. No. 40 standard sieve) that can present a fire or deflagration hazard.

8.2.2 For a static electric discharge to ignite a combustible dust, the following four conditions need to be met:

(1) An effective means of separating charge must be present.
(2) A means of accumulating the separated charges and maintaining a difference of electrical potential must be available.
(3) A discharge of the static electricity of adequate energy must be possible.
(4) The discharge must occur in an ignitible mixture of the dust.

8.2.3 A sufficient amount of dust suspended in air needs to be present in order for an ignition to achieve sustained combustion. This minimum amount is called the *minimum explosible concentration* (MEC). It is the smallest concentration, expressed in mass per unit volume, for a given particle size that will support a deflagration when uniformly suspended in air. *(In this chapter, air is assumed to be the supporting atmosphere unless another oxidizing atmosphere is specified.)*

8.2.4* In order to ignite a dust cloud by a static electric discharge, the discharge needs to have enough energy density, both in space and in time, to effect ignition. However, the term used for discharge ignition is simply that of the energy in the discharge. The minimum ignition energy (MIE) of a dust cloud is the energy in a capacitive discharge at or above which ignition can occur.

8.3 Charging Mechanisms.

8.3.1 Contact static electric charging occurs extensively in the movement of powders, both by surface friction between powders and surfaces and by friction between individual powder particles. The charging characteristics of particles are often determined as much by surface contamination as by their chemical characteristics; thus, the magnitude and polarity of a charge is difficult to predict. Charging can be expected any time a powder comes into contact with another surface, such as in sieving, pouring, scrolling, grinding, micronizing, sliding, and pneumatic conveying. In these operations, the more vigorous the contact, the more charge is generated, as shown in Table 8.3.1. The table shows that a wide range of charge densities is possible in a given operation; the actual values will depend on both the product and the operation.

Table 8.3.1 Typical Charge Levels on Medium Resistivity Powders Emerging from Various Powder Operations (before Compaction)

Operation	Mass Charge Density (µC/kg)
Sieving	10^{-3} to 10^{-5}
Pouring	10^{-1} to 10^{-3}
Auger or screw-feed transfer	10^{-2} to 1.0
Grinding	10^{-1} to 1.0
Micronizing	10^{2} to 10^{-1}
Pneumatic conveying	10^{3} to 10^{-1}

Source: British Standard 5958, *Code of Practice for Control of Undesirable Static Electricity*, Part 1, General Considerations.

8.3.2 An upper limit to the amount of charge that can be carried by a powder suspended in a gas exists. This limit is set by the strength of the electric field at the surface of the particle and depends on the surface charge density as well as the particle's size and shape. For well-dispersed particles, the maximum surface charge density is of the order of 10 $\mu C/m^2$. This value can be used to estimate maximum charge-to-mass ratios from particle diameter and density information.

8.4 Charge Retention.

8.4.1 Bulk powder can retain a static electric charge, depending on its bulk resistivity and its bulk dielectric constant. The relaxation time is expressed by the following equation:

$$\tau = \varepsilon\varepsilon_0\rho$$

where:

τ = relaxation time constant (seconds)
ε = dielectric constant of the bulked powder

ε_0 = permittivity of free space (8.85×10^{-12} sec/ohm-m)

ρ = bulk volume resistivity of the powder (ohm-m)

For historical reasons, the ability of a solid to transmit electric charges is characterized by its volume resistivity. For liquids, this ability is characterized by its conductivity.

8.4.2 Powders are divided into the following three groups:

(a) Low-resistivity powders having volume resistivities in bulk of up to 10^8 ohm-m. Examples include metals, coal dust, and carbon black.

(b) Medium-resistivity powders having volume resistivities between 10^8 and 10^{10} ohm-m. Examples include many organic powders and agricultural products.

(c) High-resistivity powders having volume resistivities above 10^{10} ohm-m. Examples include organic powders, synthetic polymers, and quartz.

8.4.2.1 Low-resistivity powders can become charged during flow. The charge rapidly dissipates when the powder is conveyed into a grounded container. However, if conveyed into a nonconductive container, the accumulated charge can result in an incendive spark.

8.4.2.2 When a medium-resistivity powder comes to rest in bulk, the charge retained depends on the resistance between the powder and ground. If the powder is placed in a grounded container, charge retention is determined by the bulk volume resistivity of the powder, which includes the interparticle resistance, as governed by the relationship given in 8.4.1. If the powder is placed in a nonconductive container, charge retention is determined by the resistance of the container. The special significance of medium-resistivity powders is that they are relatively safe during handling, because they do not produce bulking brush discharges or sparks.

8.4.2.3 High-resistivity powders do not produce spark discharges in themselves but can produce other types of discharge such as corona, brush, bulking brush, and propagating brush discharges *(see Section 4.3)*. High-resistivity powders lose charge at a slow rate, even in properly grounded containers. Many high-resistivity powders are also hydrophobic and in bulk are capable of retaining charge for hours or even days. High-resistivity powders, such as thermoplastic resins, can have bulk resistivities up to about 10^{16} ohm-m.

8.5 Discharges in Powder Operations.

8.5.1 Spark Discharge. Where spark discharges occur from conductors, the energy in the spark can be estimated from the following equations or from the nomograph in Figure 4.3.3.3:

$$W = \frac{1}{2}CV^2 \quad W = \frac{1}{2}QV \quad W = \frac{Q^2}{2C} \quad Q = CV$$

where:

W = energy (joules)

C = capacitance (farads)

Q = charge (coulombs)

V = potential difference (volts)

It should be noted that these equations apply only to capacitive discharges from conductors and cannot be applied to discharges from insulators. Discharge energies so estimated can be compared with the MIE of the dust to provide an insight into the probability of ignition by capacitive spark discharge *(see 4.3.3)*. Layers of combustible dusts can be ignited by capacitive spark discharge, and this can lead to secondary dust explosions. For a dust layer, there is no correlation with the MIE for dust cloud ignition. Capacitive spark discharges must be avoided by grounding all conductive containers, equipment, products, and personnel.

8.5.2 Corona and Brush Discharge. When handling large amounts of powder having medium or high resistivities, corona and brush discharges are to be expected. No evidence is available, however, that a corona discharge is capable of igniting a dust cloud. Likewise, no evidence is available that a brush discharge can ignite dusts with MIEs greater than 3 mJ, provided no flammable gas or vapor is present in the dust cloud.

8.5.3 Propagating Brush Discharge. Since propagating brush discharges can have energies greater than 1 J, they should be considered capable of igniting both clouds and layers of combustible dusts.

8.5.4 Bulking Brush Discharge. When powders that have resistivities greater than about 10^9 ohm-m are put into grounded conductive containers, they usually dissipate their charges by conduction at a rate that is slower than that of the charge that is accumulated in the loading process. The charge is therefore compacted, and discharges occur from the bulking point (where the particles first contact the heap) to the walls of the container. These discharges are termed *bulking brush discharges*. Experience indicates that these discharges are not capable of igniting dusts having MIEs greater than 10 mJ. However, such discharges have been attributed to explosions of dusts having MIEs less than 10 mJ.

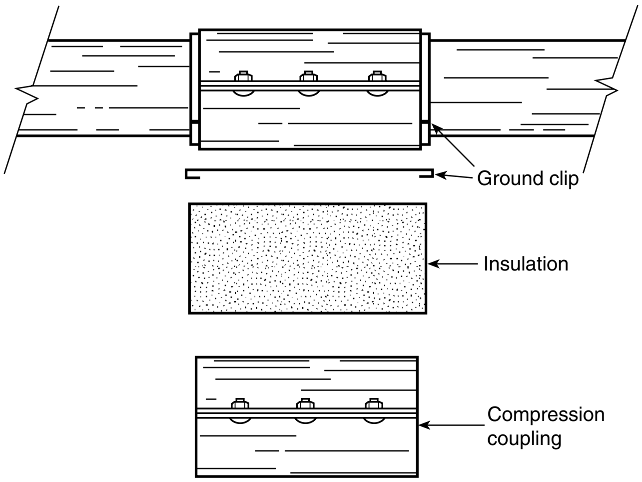
During the compaction process, the energy in the discharge increases as the particle size increases. Therefore, it can be expected that systems most at risk are those involving pellets having an appreciable fraction of fines (dust).

8.6 Pneumatic Transport Systems.

8.6.1 Pneumatic transport of powdered material through pipes or ducts can produce a static electric charge on both the product being transported and the conduit. This static electric charge will remain on the material as it exits the system. Precautions against accumulation of charge should be taken where the material is collected.

8.6.2 Pipes and ducts should be metal and should be grounded. Equipment to which the conduits connect should also be metal and grounded to dissipate the charge impressed upon it by the transport of the material. Where the use of pipe-joining methods or installation of piping components results in an interruption of continuity of the ground path, either a jumper cable should be used to maintain continuity or an independent ground should be provided for the isolated section of the conduit, as shown in Figure 8.6.2.

FIGURE 8.6.2 Compression fitting for pneumatic transport duct. *(Pratt, 1997, p. 136.)*



8.6.3 Use of nonconductive pipe or ductwork is not recommended. The use of short lengths of transparent plastic as flow visualizers is also not recommended, because they have been known to give rise to propagating brush discharges capable of igniting dusts.

8.7* Flexible Hoses. Hoses made of nonconductive material that incorporate a spiral stiffening wire should be kept in good repair to ensure that the internal wire directly contacts the metal end couplings and that the end couplings make a good connection to ground. Use of hoses with more than one internal spiral is not recommended, because determining if one of the spirals has lost its continuity is not possible.

8.8 Flexible Boots and Socks.

8.8.1 Flexible boots and socks are commonly used for gravity transfer operations. Boots are typically made of plastic or rubber, while socks are typically made of woven fabric. A nonconductive boot could give rise to either brush discharge or propagating brush discharge. Propagating brush discharge cannot happen with a sock, because of the low breakdown strength of the air gaps in the weave. However, there are conditions where socks can produce brush discharges (e.g., where used with flexible intermediate bulk containers.) *(See Section 9.1.)*

8.8.2 For combustible dusts, the end-to-end resistance of boots and socks should be less than 10^8 ohms and preferably less than 10^6 ohms, measured with a megohmmeter.

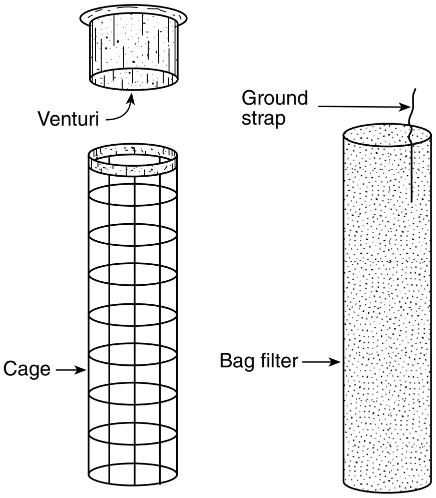
8.8.3 Flexible connections should not be depended on for a bond or ground connection between process equipment. Separate bonding or grounding connections should be used.

8.9 Bag Houses.

8.9.1 As dusts are drawn or blown into a bag house, they necessarily carry with them a static electric charge, the magnitude of which depends on the characteristics of the dust and the process, as illustrated in Table 8.3.1. The charge will remain on the dust and will accumulate on the surfaces of the bags. It is therefore important to keep all conductive equipment grounded to prevent the induction of this accumulated charge onto conductive components that could have inadvertently become ungrounded. Such induction is particularly true in the case of cage assemblies.

8.9.2 If cage assemblies are not well grounded, capacitive spark discharge can occur from the ungrounded cages to either the structure of the bag house or to adjacent cage assemblies. Many times the bags have metal braid pigtails attached to their cuffs, the notion being that the pigtail can be simply brought through the cage and bonded to the tube sheet. This method of grounding the cage is not always successful. Furthermore, the reason for the pigtail is often misunderstood. Because the bag is nonconductive, the bag itself is not grounded. It is therefore useless to extend the metal braid down the entire length of the bag. *(See Figure 8.9.2.)*

FIGURE 8.9.2 Arrangement of cage and filter bag. *(Pratt, 1997, p. 134.)*



8.9.3 Bags and cages should be engineered so that a positive ground connection is always maintained during maintenance, even with inexperienced or inattentive personnel. One way of doing this is by sewing two metal braids into the cuffs of the bags, 180 degrees apart. Each braid is continuous and is sewn up the inside of the cuff, across the top, and down the outside of the cuff. By doing this, the braids will always make a positive contact with the cage, the venturi, and the clamp and will withstand the rigors of the operation. In any case, the resistance between the cage and ground should be less than 10 ohms.

8.9.4 No evidence is available that filter bags made from conductive or antistatic fabric are needed to prevent incendive discharges. On the contrary, such bags could create discharge hazards if sections of the fabric become isolated or if a bag falls into the bottom of the bag house.

8.10* Hybrid Mixtures.

8.10.1 The term *hybrid mixture* applies to any mixture of suspended combustible dust and flammable gas or vapor, where neither the dust itself nor the vapor itself is present in sufficient quantity to support combustion, but the mixture of the two can support combustion. Hybrid mixtures pose particular problems because they combine the problems of the large charge densities of powder-handling operations with the small ignition energies of flammable vapors. The MIE of a hybrid mixture is difficult to assess, but a conservative estimate can be made by assuming that the MIE of the mixture is at or near the

MIE of the gas alone. Because hybrid mixtures contain a flammable gas or vapor, they can be ignited by brush discharge.

8.10.2 Powders that contain enough solvent (i.e., greater than 0.2 percent by weight) so that significant concentrations of solvent vapor can accumulate in the operations in which they are handled are termed *solvent-wet powders.* Consideration should be given to applying the recommendations of Chapter 7 to solvent-wet powders, unless the resistivity of the solvent-wet product is less than 10^8 ohm-m.

8.11* Manual Addition of Powders to Flammable Liquids.

8.11.1 The most frequent cause of static electric ignitions in process vessels is the addition of solids to flammable liquids in the vessels. Even when the vessel is inerted, large additions of solids will introduce air into the vessel while expelling flammable vapor from the vessel. The sudden addition of a large volume of solids can also result in static discharge from a floating pile of charged powder. It is recommended that manual addition of solids through an open port or manway be done only in 25-kg batches. Larger batch additions [e.g., from flexible IBCs *(see 9.1.7)*] should be done through an intermediate hopper with a rotary valve or an equivalent arrangement. The hopper can be separately inerted to reduce air entrainment into the mixing vessel while expulsion of vapor into the operating area can be avoided by venting the vessel to a safe location. The addition of solids from nonconductive plastic bags can be hazardous even if the solids are noncombustible (e.g., silica). Bags should be constructed of paper, plies of paper and plastic in which the nonconductive plastic film is covered by paper on both sides, or antistatic plastic. Because grounding clips can be impractical, such bags can be effectively grounded by contact with a grounded conductive vessel or by skin contact with a grounded operator. Fiber drums or packages should not have a loose plastic liner that can leave the package and behave like a plastic bag. Metal chimes should be grounded. Personnel in the vicinity of openings of vessels that contain flammable liquids should be grounded, and special attention should be paid to housekeeping, because accumulation of nonconductive residues (e.g., resins) on the floor or on items such as grounding clips can impair electrical continuity.

8.11.2 Powder should not be emptied from a nonconductive container in the presence of a flammable atmosphere. Direct emptying of powders from nonconductive plastic bags into a vessel that contains a flammable atmosphere should be strictly prohibited.

8.11.3 Where a thorough understanding of the process exists and where the vessel does not contain an ignitible atmosphere, adding the powder to the vessel before adding the liquid might be practical.

8.12 Bulk Storage. When powders are moved into bulk storage (e.g., silos, rail cars, trucks, IBCs, or flexible IBCs), the powder is compacted by the force of gravity. The compaction process is accompanied by bulking brush discharge, as explained in 8.5.4. In the compaction process, the energy of the discharge increases as the particle size increases. Therefore, the systems most at risk are pellets with an appreciable fraction of fines (dust).

The exact conditions for ignition-capable bulking brush discharge are not well understood. However, the following general factors that are known to increase its probability have been identified by Glor in *Electrostatic Hazards in Power Handling:*

(1) An increase in the resistivity of the powder, greater than 10^{10} ohm-m
(2) An increase in the particle size of the powder, greater than 1 mm
(3) An increase in the charge density of the powder, greater than 1 μC/kg
(4) An increase in filling rate — for granules with a diameter greater than 1 mm to 2 mm, greater than 2×10^3 kg/hr, and for granules with a diameter of about 0.8 mm, greater than 20 to 30×10^3 kg/hr

Chapter 9 Specific Applications

9.1 Intermediate Bulk Containers.

9.1.1 The discussion and precautions for powders and granular solids, as set forth in Chapter 8, also apply to operations that involve handling these materials in intermediate bulk containers (IBCs). Static electric charges are generated in granular materials when filling and emptying IBCs. These charges result from movement and rubbing of the granules against process equipment or against each other. The amount of charge that can be accumulated on a bed of a powdered material in a grounded container depends on the resistivity of the powder, not the resistivity of a block of the material. The higher the resistivity, the lower the apparent conductivity and the longer a charge will be retained. In cases of very large resistivities, charges will relax slowly and can remain on beds of material for appreciable periods. Thus, generation and relaxation occur simultaneously when granular materials are moved about. When the rate of generation exceeds the rate of relaxation, significant charges can accumulate.

9.1.2 When a static electric charge accumulates on bulk containers or associated process equipment, the following four types of discharge can occur:

(1) Spark discharge
(2) Brush discharge
(3) Propagating brush discharge
(4) Bulking brush discharge

(See Section 4.3 for discussions of these four types of discharge.)

9.1.2.1 Spark discharges can take place between two conductors at different potentials and can release energy capable of igniting atmospheres containing flammable gases or vapors or combustible dusts, depending on process conditions. An example of a situation in which such a discharge can occur is a conductor that is isolated from ground and located in a bin of material.

9.1.2.2 Brush discharge is usually not a concern in the normal handling of granular materials. However, brush discharge can be a source of ignition where flammable gases or vapors are present, as in the handling of hybrid mixtures or very rapid discharge of a granular material from a container. Such situations should be avoided if possible.

9.1.2.3 Propagating brush discharges typically contain energies of 1 J or greater, depending on process conditions. These discharges can ignite most flammable atmospheres.

9.1.2.4 Bulking brush discharges contain energies on the order of 10 mJ. In order to minimize the risks associated with bulking brush discharge, powders that have minimum ignition energies of 10 mJ or less should only be loaded into containers of 2 m^3 or less, unless the vessel is inerted.

9.1.3 If a granular material contains only particles larger than 420 μm, then ignitible dust clouds cannot be formed. However, if a granular material consists of fine particles or contains an appreciable fraction of fine particles, then ignitible dust suspensions can be formed and ignition sources cannot be tolerated.

9.1.4 Experience has shown that, where powders have resistivities of less than 10^8 ohm-meters, static electric charges usually relax rapidly enough to prevent their accumulation in the bulk granular material.

9.1.5 Conductive Intermediate Bulk Containers.

9.1.5.1 Conductive IBCs (e.g., those constructed of metal) should be grounded during all operations in areas where an ignitible atmosphere exists. Engineering and administrative controls should be considered to ensure that grounding of conductive containers and associated conductive equipment is accomplished during all operations. For example, metal funnels should be grounded and flexible fill pipes should have any conductive components, including any internal stiffening wires, connected to ground.

9.1.5.2 When a nonconductive material is transferred into a conductive IBC that is grounded, any charge that has accumulated on the material will remain on the material. The process of relaxation is the slow migration of the charges through the material to the opposite charges on the wall. While this relaxation process is occurring, which can last a few seconds or many minutes depending on the conductivity of the material, an electric field still exists at the surface of the material. In the case of IBCs with open tops, this electric field can induce charges on other conductors that might be present, including ungrounded personnel. Thus, induction of surface charges onto other ungrounded conductors can occur even when conductive IBCs are properly grounded. Appropriate precautions should be taken.

9.1.5.3 IBCs made of conductive materials and nonconductive liners should be used only if the liners are essential (e.g., to maintain compatibility between the IBC and the material being handled.) The risk of ignition and the possibility of electric shock from propagating brush discharge depend very much on the thickness and resistivity of the liner, the handling procedure, the electrical properties of the material being handled, and the incendive nature of any combustible material that might be present. In general, propagating brush discharge will not occur, provided the nonconductive liner has a breakdown voltage lower than 4 kV. Each situation should be considered individually.

9.1.6 Nonconductive Intermediate Bulk Containers.

9.1.6.1 The term *nonconductive* applies to any IBC that has a volume resistivity greater than 10^{10} ohm-m or a surface resistivity greater than 10^{11} ohms.

9.1.6.2 When a material is transferred into a nonconductive IBC, the container material will hinder the relaxation to ground of any static electric charge that is present on the material. In this instance, even conductive contents can accumulate charge.

9.1.6.3 Nonconductive IBCs should not be filled or emptied in areas where easily ignitible atmospheres (i.e., minimum ignition energy less than 10 mJ) are present (i.e., gases, flammable vapors, sensitive dusts, and hybrid mixtures.) When powders are to be added to flammable liquids from nonconductive containers, the receiving system should be closed and inerted.

9.1.6.4 Nonconductive IBCs should not be used with solvent wet powders in locations where the ambient temperature is near or above the flash point of the solvent. Powders should be considered to be solvent-wet powders if they contain more than 0.2 percent by weight of solvent.

9.1.6.5 If a nonconductive IBC is moved into a location where flammable gases or vapors are also present, rubbing of the container should be avoided.

9.1.7 Flexible Intermediate Bulk Containers (FIBCs).

9.1.7.1 Description. Flexible intermediate bulk containers (FIBCs) are basically very large fabric bags supported in a frame. They are more convenient than rigid IBCs because they can be fully collapsed after use, taking up little storage space. The fabric is usually polypropylene and the fabric is sewn to form a three-dimensional cube or rectangle with lifting straps. A FIBC can be filled with a powder or granular material and moved about with conventional materials-handling equipment. An advantage of FIBCs is that they can be unloaded very quickly, typically 300 kg to 500 kg in 30 seconds or less. Therefore, rates at which static electric charges are generated can often exceed the rates at which the charges can relax under common conditions of use and accumulation of a static electric charge can be expected. In general, the precautions given in this subsection for IBCs also apply to FIBCs.

9.1.7.2 Charge Generation. Static electric charges can be generated during filling and emptying of FIBCs and can accumulate on both the contents and the fabric of the FIBC. If the accumulated charge is strong enough and is released in the presence of an ignitible atmosphere, ignition can occur.

9.1.7.3 Nonconductive FIBCs. FIBCs constructed of nonconductive materials (e.g., polypropylene fabric with polyester stitching) have no special features incorporated in their design to minimize static electric charging. These nonconductive FIBCs can be used for materials that do not form ignitible atmospheres in normal handling operations. Experience has shown that granular materials that do form dust clouds during handling can also be safely handled in these FIBCs, provided the dust clouds generated cannot be easily ignited by a static electric discharge. In other words, the material should have an MIE for a dust cloud that is greater than 100 mJ. These FIBCs should not be used for granular materials that have a minimum ignition energy less than 100 mJ and should never be used in areas where a flammable gas or vapor is present.

9.1.7.4 Conductive FIBCs.

9.1.7.4.1 FIBCs constructed of conductive fabric can be treated the same as conductive IBCs, as specified in 9.1.5. If conductive FIBCs are used with a liner, the recommendations of 9.1.5.3 also apply. It is essential that these FIBCs be grounded during all operations.

9.1.7.4.2 FIBCs constructed of nonconductive fabric and containing woven, grounded, conductive filaments can be considered to be conductive. One type has conductive filaments that are spaced less than 20 mm apart, each of which is connected at least once to its neighbor, preferably at one end, and are intended to be grounded. Another type has conductive filaments or threads that form an interconnecting grid of not more than 50 mm mesh size and are also intended to be grounded. The recommendations for conductive IBCs given in 9.1.5 also apply to these FIBCs. A grounding tab that is electrically connected to the conductive threads is provided and is intended to be connected to a ground point when the FIBC is filled or emptied.

9.1.7.5 Summary. At the present time, the manufacture and use of FIBCs is in a development stage and many variants and combinations of fabric are being introduced. It is, therefore, not possible to make recommendations for the safe use of all the types being used in areas where an ignitible atmosphere might be present. In particular, at this time, sufficient data are not available for FIBCs constructed of layers of various conductive and nonconductive fabrics.

9.1.8 Container Linings.

9.1.8.1 Both conductive and nonconductive liners are used in containers. Conductive liners (e.g., carbon-filled polyethylene) have been used inside nonconductive containers in order to provide a means for grounding. In instances where product contamination is a concern, nonconductive (e.g., polyethylene) liners have been used in both conductive (e.g., metal) and nonconductive (e.g., polypropylene) containers. And, in instances where very fine powders can leak through the weave of the cloth, nonconductive (e.g., polyethylene) liners have been used.

9.1.8.2 Extreme caution should be exercised when using conductive liners to ensure that they do not become ungrounded. As in the case of conductive containers, conductive liners should be grounded during all operations.

9.1.8.3 In the handling of materials that accumulate static electric charges, the use of liners that have resistivities greater than 10^{11} ohms inside conductive containers could create conditions where propagating brush discharges or capacitor-like discharges can occur. Because the conditions under which these discharges can occur are many and varied, no general recommendations can be given at this time.

9.1.8.4 Where using nonconductive liners in nonconductive containers, the precautions required are the same as for nonconductive containers alone, as given in 9.1.7 and 9.1.8.3.

9.1.8.5 Liners should never be removed from containers (e.g., to shake out a residue) where easily ignitible atmospheres (i.e., MIE less than 30 mJ) are present (e.g., gases, flammable vapors, sensitive dusts, and hybrid mixtures).

9.2 Web and Sheet Processes.

9.2.1 General. In web processes such as printing, coating, spreading, and impregnating, static electricity is a frequent, annoying, and often expensive source of production problems. If flammable solvents are used in the process, static electric charges can constitute an ignition source.

In practice, paper or any other substrate charged with static electricity will attract or repel other objects. This phenomenon can cause difficulty in controlling the sheet or web, which is the continuous substrate that is being printed or coated. It can also cause problems with delivering and handling the printed product due to static attraction between the sheets or folded signatures. Static electric charges can transfer by induction or by contact with various objects (e.g., during handling of the paper or substrate by personnel). This static electric charge can accumulate on a person who is not adequately grounded.

9.2.2 Substrates.

9.2.2.1 Paper. The characteristics of the surface of the paper have a great deal to do with the amount of static electric charge that is generated during processing. Generally, printing on paper causes fewer problems than printing on plastic substrates and other synthetic materials. Static electric charge accumulates on paper during the handling process. On presses and in other handling operations, static electric charge can be generated by belts driving the paper rolls, sliding of the web over idler rollers and angle bars, motion of the web through a nip, and motion of brushes and delivery belts in the folder. In some operations, static electric charge is deliberately deposited on the web to improve certain operations such as material deposition and sheet transfer. In gravure printing, for example, electrostatic assist is used to improve the transfer of ink. On high-speed offset and high-speed gravure presses, ribbon tacking is used to control the ribbons and signatures in the folder.

9.2.2.2 Plastics. Most plastic films are characterized by extremely high surface and bulk resistivities. This resistivity allows static electric charge to accumulate on the web after contact with machine parts, such as rollers and belts, with little dissipation occurring.

9.2.2.3 Fabrics and Nonwovens. Fabrics are usually made of blends of natural fibers (usually hygroscopic and capable of relaxing a charge) and synthetic fibers (usually highly resistive and capable of holding a charge). The less the proportion of natural fibers, the greater the incidence of static electric problems in subsequent operations. Fabrics are thin, like paper and plastic films, and accumulate static electricity in a similar manner. Nonwovens often have a loft that gives them a three-dimensional structure. They are almost exclusively synthetic, so they tend to generate and hold substantial charges in the forming process. These charges can be more difficult to remove due to the depth of the loft. In a subsequent coating or saturating process, large amounts of charge can again be generated due to relative motion of the fibers and, again, it can be difficult to remove if the loft returns. The solvent-wet batt contains a relatively large volume of flammable vapor and electrostatic discharge can cause ignition.

9.2.3 Inks and Coatings.

9.2.3.1 Inks used in letter presses and offset presses are typically Class IIIB liquids that have flash points above 200°F and present little fire or explosion hazard. However, inks used in silk screen, rotogravure, and flexograph printing are usually Class IB and Class IC liquids with flash points less than 100°F. Fires can occur in these inks due to the use of solvents whose vapors can be ignited by static electric discharge, as well as by other ignition sources.

9.2.3.2 The solutions and suspensions that are used to coat and saturate webs are diverse. While they are still wet, water-based coatings are generally conductive enough to dissipate any charge that is generated in the process, even though there might be minor concentrations of solvent present that can create an ignitible vapor layer on the web. When dry, however, these coatings are not always capable of dissipating the charge, but vapors are seldom left at this point.

9.2.3.3 Flammable solvent-based inks and coatings should be considered nonconductive and, therefore, incapable of dissipating a charge. Conductivity enhancers in the ink or coating cannot be relied on to assist dissipation of charge at high processing speeds. Measurement of coating solution conductivity can provide additional data to determine static generation and dissipation characteristics.

9.2.3.4 Black inks used in gravure printing are generally nonconductive. When accumulations of black ink, particularly those used on uncoated papers, are washed or cleaned off the rubber impression rollers, the resin can be washed out of the ink buildup, leaving a residue of conductive carbon (i.e., the pigment). If this conductive residue is not thoroughly wiped off the rollers, sparking and arcing from the roller to the cylinder or other grounded press parts can occur.

9.2.4 Processes.

9.2.4.1 Printing Presses. All other factors being equal, printing presses that operate at higher speeds generate more static electricity. A rotogravure press, for example, can generate static electric where the rubber roll presses the substrate against an engraved roll, which is wetted with the ink. Charge can be transferred from the engraved roll to the substrate. In a multicolored press, there is a similar arrangement for each color. The generation of charge is a function of the pressure between the rolls and the angle to the roll. The electrostatic assist (ESA) process, when used, deposits large amounts of charge onto the substrate. Note that ESA equipment must be suitable for Class I, Division 1 locations.

9.2.4.2 Coating. Coating of web materials is done using a wide variety of equipment. Some of these processes can generate hazardous amounts of static electric charge due to their design while others cause little effect. The operating conditions that cause high rates of charge generation include high forces between rollers and the web, such as in gravure coating. This high rate of generation is aggravated by maintaining a tension difference across the coating roller, which causes slippage. The result is a sizable charge at the point where a large amount of ignitible vapor and liquid surface area is present. The rubber backup roller can accumulate enough electrostatic charge to present an ignition hazard. An electrostatic charge neutralizer might be required on the roller.

9.2.4.3 Saturating. Saturating is the process of immersion of a web in a liquid so that the liquid fills the pores in the web. The excess liquid is then squeezed or wiped from both sides of the web. Electrostatic charging during saturating operations is not usually a problem for most webs. When the web is a nonwoven with substantial loft and the liquid is flammable and of low conductivity, a static electric hazard can be created.

9.2.4.4 Calendaring. Calendaring is a process by which a substrate is squeezed at high pressure between rollers that are generally smooth. This process is used to create a dense product with a smooth surface, such as magazine cover stock. It is also used to mill and form webs from materials such as rubber and plastics. The intimate contact caused by the high pressures and the working of the materials between the nipped rollers creates charge on the web. Charging can be high enough to form corona discharge at the exit of the nip.

Because flammable solvents are not usually present, the effect of static electric charge is to cause operator shock and web-handling problems. Static neutralizers can effectively remove the charge.

9.2.4.5 Web Handling and Converting. The path of the web through processing machinery often is guided over many rollers. Movement of the web over these rollers produces static electric charge due to friction. A freely turning idler roller imparts little charge to the web. As the speed of the process increases above 200 ft/min, air is drawn between the web and the roller, reducing the intimacy of contact and, thus, the rate of charge generation. If the roller does not turn freely, however, the web slips on the roller surface and can generate a large static electric charge. Periodic inspections and maintenance should be performed to ensure that the rollers are always free-turning.

Converting large rolls of web goods to finished product involves operations such as slitting, sheeting, folding, and packaging. These operations involve many contacting surfaces, and materials used to construct machinery for them are chosen for durability and resistance to wear more so than for static electric characteristics. The machinery is designed to occupy a minimum of floor area for economy of plant space. The machines are dense with rollers, belts, and framework that variously generate charge and suppress static electric charge and provide minimal space to install static electricity neutralizers. The result is a static electric problem that can be hard to measure and hard to control. Problems include the following:

(1) Product sticking or flying
(2) Machine jams
(3) Misaligned product stacks
(4) Bad product rolls
(5) Bad packages

With photosensitive materials, the charge can cause product damage, which is only revealed when the customer complains.

9.2.4.6 Ribbon Tacking. On high-speed offset and gravure presses, high-voltage tacking is used to improve the delivery of signatures to the folder. These high-voltage devices should be suitable for Class II, Division 2 locations if subject to accumulations of settled paper dust.

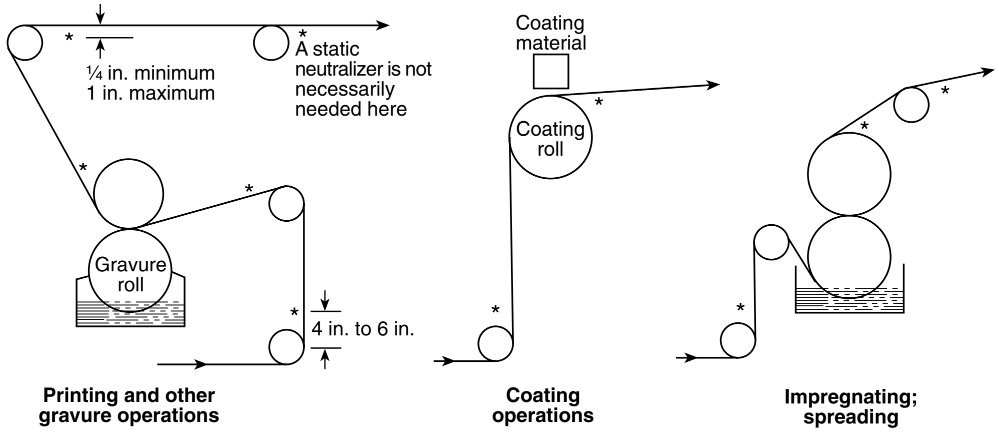
9.2.5 Control of Static Electricity in Web Processes.

9.2.5.1 Higher operating speeds result in the potential for increased volumes of flammable vapors in the immediate vicinity of the area where flammable liquids are applied to the substrate. Coating technology such as the enclosed ink gravure fountain has minimized the volume of flammable vapors in the application area. Solvent vapors can be diluted below the LFL by means of mechanical ventilation. The performance of the ventilation system is optimized by capturing vapors as close to their source as possible. The ventilation system should be interlocked with the equipment to ensure safe operation of the process. Vapors will always be within the flammable range in the areas close to the application process and the substrate.

9.2.5.2 A common method of removing static electric charge from processing machinery is by grounding the machine. All conductive parts of the machine should be electrically bonded together for this method to be effective. It should be noted that the charge on the material being processed is not removed by this grounding and bonding.

9.2.5.3 The ionization method of charge neutralization is the most effective means for controlling static electric charge on the webs in presses and coaters. Neutralizers, also called static elimination bars or inductive ionizers, are commonly used close to the substrate, but they should not touch the substrate. The reduction of charge at any one point in the operation does not prevent generation of charge in later steps of the process. Static neutralizers might be necessary at a number of locations *(see Figure 9.2.5.3)*.

FIGURE 9.2.5.3 Typical locations for static control.



Printing and other gravure operations

Coating operations

Impregnating; spreading

*Suggested locations for static neutralizers.

High-speed operations might require a second static neutralizer at a single location, but providing more than two usually gains no additional benefit. Neutralizers should extend across the full width of the web. For fast-running presses, inductive neutralizers, such as tinsel wrapped around a bar or grounded needle points, spaced 12 mm to 25 mm apart and placed at the inlet and delivery side of each impression roller, 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 charge or voltage. An area of web as small as 0.01 m^2 or an area of 115 mm in diameter might be capable of releasing an incendive discharge. The neutralizer should be installed as far as possible from grounded metal machine parts or areas where the web is supported by rollers. The recommended location of the initial inductive ionizer is 100 mm to 175 mm from the roller tangent (i.e., web exit) point and 6 mm to 25 mm from the web. Thus, the first neutralizer after the roller might have to be placed so close to the roller that it is partially suppressed from ionizing but can minimize the area of high charge. An additional ionizer or two downstream from the roller might also be necessary to reduce the charge to the desired extent. Final location near critical rollers should be determined by adjustment and measurement to minimize web charge, as indicated by apparent voltage.

9.2.5.4 Tinsel or needle points remain functional only as long as they are clean and sharp. Accumulation of contaminants (e.g., ink, coating solution, or paper dust) and corrosion products should be controlled by an effective maintenance program. Visual inspection and performance verification of the neutralizers should be done at intervals that will depend on how process conditions affect performance of the neutralizers.

9.2.5.5 Humidification has been used in the past to decrease static electric charge on materials in the environment, such as in garments and floor coverings. However, with modern high-speed operations, nonconductors, such as paper and plastic films, cannot adsorb enough moisture from the atmosphere during the brief time that they are exposed to humid air to increase their surface conductivity. Plastics generally do not become sufficiently conductive, even in humid atmospheres, due to lack of ionized molecules in an acquired surface layer of moisture. Therefore, humidification is not a recommended method of control of static electricity in such processes.

9.3 Spray Application.

9.3.1 Processes that involve spray application of liquids or powders (e.g., paints, coatings, lubricants, and adhesives) can cause accumulation of static electric charges on the spray apparatus and on the surfaces of the objects being sprayed and other objects in the spray area. If the material sprayed is ignitible, then static electric discharge can result in ignition.

9.3.2* Personnel involved in operating or servicing electrostatic spray application equipment should be trained in the operating procedures recommended by the manufacturer of the equipment and in the control of hazards associated with the materials being sprayed and their residues.

9.4 Belts and Conveyors.

9.4.1 General. Flat or "V"-shaped rubber or leather belts used for transmission of power or belts used for the transportation of solid materials can generate static electric charges that warrant corrective measures if a possibility exists that ignitible concentrations of flammable gases or vapors or combustible dusts or fibers might be present. The amount of charge generated will increase as any of the following increase:

(1) Belt speed
(2) Belt tension
(3) Width of the contact area

9.4.2 Flat Belts.

9.4.2.1* Synthetic, rubber, or leather flat belts are usually good insulators because they are dry when operated and because they operate at elevated temperatures due to friction. Generation of static electric charge occurs where the belt leaves the pulley and can occur with either conductive or nonconductive pulleys.

9.4.2.2* Accumulation of static electric charge on belts can be prevented by using belts made of conductive materials or by applying a conductive dressing to the belt. If a dressing is used, it should be reapplied frequently or the conductivity of the belt will diminish. In either case, belts should be kept free of accumulations. It should be noted that both conductive and nonconductive belts can generate and deposit charge on the material or objects being conveyed.

9.4.2.3 An electrostatic neutralizer placed so that the points are close to the inside of the belt and a few inches away from the point where the belt leaves the pulley will also be effective in draining away most of the charge. *(See 9.2.5.3.)*

9.4.3* "V" Belts. V belts are not as susceptible to hazardous accumulations of static electric charge as are flat belts. Under certain conditions of temperature and humidity, however, a V belt can generate a significant charge. Where ignitible mixtures of gases, vapors, dusts, or fibers are present, the preferred method to limit ignition by static electric discharge is to use a direct drive instead of a belt. If a V belt is necessary for other reasons, it should be protected in accordance with 9.4.2.2.

9.4.4 Conveyor Belts.

9.4.4.1 Belts used for the transport of solid materials usually move at speeds that are slow enough to prevent an accumulation of static electric charges. However, if the material being transported is very dry or if the belt operates in a heated environment and at high speeds, significant charges can be generated.

9.4.4.2 Material that is spilled from the end of a conveyor belt into a hopper or chute can carry a significant charge. In these cases, the belt support and terminal pulleys should be electrically grounded or bonded to the hopper or chute. A passive or active neutralizer installed close to the end of the conveyor can also help reduce the charge. Conductive or antistatic belts cannot be expected to remove static from the conveyed product.

9.4.5 Pulleys and Shafts.

9.4.5.1 Metal pulleys can accumulate a charge equal and opposite to that carried by the belt that runs over them, and this charge typically will pass to the supporting shaft and then through bearings to the equipment and to ground. Where nonconductive components isolate metal parts, separately bonding or grounding those parts could be necessary.

9.4.5.2 Lubricated bearings are still sufficiently conductive to allow dissipation of a static electric charge from the shaft. However, the conductivity across bearings that operate at very high speed is not necessarily sufficient to prevent accumulation of charge when the rate of generation is also high. For this reason, shafts that rotate at high speed should be checked for accumulation of static electric charge and should be bonded or grounded by means of a sliding metal contact to the housing, if necessary.

9.4.5.3 The effective resistance across a bearing while in operation can be measured with a common ohmmeter. One of the probes should be placed on the grounded machine frame and the other probe should be allowed to rest against the rolling member. A value of approximately 10^4 ohms is to be expected. If a value greater than 10^5 ohms is found, an auxiliary grounding brush or shoe might be needed to prevent changes with time that could exceed 10^6 ohms. The grounding brush needs periodic checking and maintenance. Critical bearings without a brush should be measured periodically.

9.4.6 Maintenance of Belts and Conveyors. Belts and conveyors should be inspected frequently for slipping or jamming to lessen the chance of generation of static electricity. Drive systems should be designed to stall without slipping when operating in hazardous environments. Lubricant does not prevent the removal of static electric charges. Therefore, all bearings should be properly lubricated. However, the flow of static electricity across the film of lubricant sometimes results in pitting of bearing surfaces. A conductive grounded brush running on the shaft or pulley will prevent pitting of the bearings.

9.5 Explosives. Most explosives and materials used as solid propellants contain enough oxidizer to sustain an explosive reaction without any outside contribution. These materials typically are sensitive to static electric discharge and can be extremely hazardous to handle if suitable precautions are not taken. In addition to the recommendations contained in this recommended practice, the following documents should be consulted for more specific information:

(1) NFPA 495, *Explosive Materials Code*
(2) NFPA 498, *Standard for Safe Havens and Interchange Lots for Vehicles Transporting Explosives*
(3) NFPA 1124, *Code for the Manufacture, Transportation, and Storage of Fireworks and Pyrotechnic Articles*
(4) NFPA 1125, *Code for the Manufacture of Model Rocket and High Power Rocket Motors*
(5) U.S. Department of Defense Standard 6055.9, *Ammunition and Explosive Safety Standards*
(6) U.S. Department of Defense Standard 4145.26M, *Contractors' Safety Manual for Ammunition and Explosives*
(7) IME Safety Library Publication No. 3, *Suggested Code of Regulations for the Manufacture, Transportation, Storage, Sale, Possession, and Use of Explosive Materials*
(8) IME Safety Library Publication No. 17, *Safety in the Transportation, Storage, Handling, and Use of Explosive Materials*

9.6 Cathode Ray Tube Video Display Terminals.

9.6.1 A static electric charge is commonly present on the face of cathode ray tube (CRT) video display terminals, particularly on color monitors and color television screens. This charge is the direct result of the CRT's high-energy electron beam "writing" the image on the inside surface of the screen. The charge accumulates on the nonconductive surface of the screen and can reach energies capable of igniting a flammable atmosphere, if discharge occurs. Such an atmosphere can be created by wiping the screen of an operating or recently operated CRT with a cloth or tissue that is wet with commercial cleaners that typically contain a flammable liquid such as isopropyl alcohol or by using spray-on aerosol cleaners that use a flammable gas propellant. The static electric charge can be removed from the screen of the CRT by accessories or by proper procedures *(see 9.6.3)*. Other video display terminals, such as liquid crystal displays, gas plasma displays, and vacuum fluorescent displays, do not present similar static electric effects. This does not mean, however, that these displays are intrinsically safe for use in hazardous locations.

9.6.2 In an industrial environment that is classified as hazardous in accordance with Article 500 of NFPA 70, *National Electrical Code*®, only engineering methods are acceptable for controlling the hazard. Due to the high voltages present, the CRT should be enclosed in a purged or pressurized enclosure, as described in NFPA 496, *Standard for Purged and Pressurized Enclosures for Electrical Equipment.* To protect against a static electric discharge from the screen's surface, the screen cannot be exposed to the surrounding environment but should be located behind a window in the enclosure.

9.6.3 In nonhazardous locations, a commercial static electric dissipating screen that overlays the CRT screen can be used to drain the static electric charge by means of a connection to ground. The ground connection from the overlay should be secure to prevent shock or an ignition-capable spark. One safe procedure for reducing the charge on the CRT screen is to wipe the screen with a water-wet cloth or tissue immediately before using any solvent-based cleaners. This action will drain off the excess charge through the operator's body. Ideally, nonflammable or low-volatility cleaning agents should be used.

Chapter 10 Referenced Publications

10.1 The following documents or portions thereof are referenced within this recommended practice and should be considered as part of its recommendations. The edition indicated for each referenced document is the current edition as of the date of the NFPA issuance of this recommended practice. Some of these documents might also be referenced in this recommended practice for specific informational purposes and, therefore, are also listed in Appendix E.

10.1.1 NFPA Publications. National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101.

NFPA 30, *Flammable and Combustible Liquids Code*, 2000 edition.

NFPA 33, *Standard for Spray Application Using Flammable or Combustible Materials*, 2000 edition.

NFPA 53, *Recommended Practice on Materials, Equipment, and Systems Used in Oxygen-Enriched Atmospheres*, 1999 edition.

NFPA 69, *Standard on Explosion Prevention Systems*, 1997 edition.

NFPA 70, *National Electrical Code*®, 1999 edition.

NFPA 99, *Standard for Health Care Facilities*, 1999 edition.

NFPA 326, *Standard for the Safeguarding of Tanks and Containers for Entry, Cleaning, or Repair*, 1999 edition.

NFPA 495, *Explosives Materials Code*, 1996 edition.

NFPA 496, *Standard for Purged and Pressurized Enclosures for Electrical Equipment*, 1998 edition.

NFPA 498, *Standard for Safe Havens and Interchange Lots for Vehicles Transporting Explosives*, 1996 edition.

NFPA 1124, *Code for the Manufacture, Transportation, and Storage of Fireworks and Pyrotechnic Articles*, 1998 edition.

NFPA 1125, *Code for the Manufacture of Model Rocket and High Power Rocket Motors*, 1995 edition.

10.1.2 Other Publications.

10.1.2.1 AIChE Publication. American Institute of Chemical Engineers, 3 Park Avenue, New York, NY 10016-5901.

Britton, L. G., "Using Material Data in Static Hazard Assessment," *Plant/Operations Progress*, April, 1992.

10.1.2.2 API Publication. American Petroleum Institute, 1220 L Street, NW, Washington, DC 20005.

RP 2003, *Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents*, 6th edition, 1998.

10.1.2.3 ASTM Publication. American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM D 257, *Standard Test Methods for DC Resistance or Conductance of Insulating Materials*, 1999.

10.1.2.4 CENELEC Publication. CENELEC, Rue de Stassart, 35, B – 1050 Brussels, Belgium.

EN 61241-2-2, *Electrical Apparatus for Use in the Presence of Combustible Dust — Part 2: Test Methods; Section 2: Method for Determining the Electrical Resistivity of Dust in Layers*, International Electrotechnical Commission, Brussels, 1993.

10.1.2.5 IME Publications. Institute of Makers of Explosives, 1120 Nineteenth Street, NW, Suite 310, Washington, DC 20036-3605.

Safety Library Publication No. 3, *Suggested Code of Regulations for the Manufacture, Transportation, Storage, Sale, Possession, and Use of Explosive Materials.*

Safety Library Publication No. 17, *Safety in the Transportation, Storage, Handling, and Use of Explosive Materials.*

10.1.2.6 JIS Publication. Japan Industrial Standards.

JIS B 9915, *Measuring Methods for Dust Resistivity (with Parallel Electrodes)*, Japan Industrial Standards, Tokyo, 1989.

10.1.2.7 NPCA Publication. National Paint and Coatings Association, 1500 Rhode Island Avenue, NW, Washington, DC 20005.

Generation and Control of Static Electricity, 3rd edition, 1988.

10.1.2.8 U.S. Department of Defense Publications. U.S. Government Printing Office, Washington, DC 20402.

Standard 4145.26M, *Contractors' Safety Manual for Ammunition and Explosives.*

Standard 6055.9, *Ammunition and Explosive Safety Standards.*

10.1.3 Additional Publications.

10.1.3.1 BS 5958, *Code of Practice for Control of Undesirable Static Electricity*, Part 1, General Considerations, British Standards Institution, London, 1991.

10.1.3.2 Glor, M., *Electrostatic Hazards in Powder Handling*, Research Studies Press, Ltd., Letchworth, Hertfordshire, England, 1988.

10.1.3.3 *International Safety Guide for Oil Tankers and Terminals*, Fourth Edition, Witherby and Co., Ltd., London, 1996.

10.1.3.4 Pratt, T. H., *Electrostatic Ignitions of Fires and Explosions*, Burgoyne, Inc., Marietta, GA, 1997.

10.1.3.5 Walmsley, H. L., "Avoidance of Electrostatic Hazards in the Petroleum Industry," *Journal of Electrostatics*, Vol. 27, No. 1 and No. 2, Elsevier, New York, 1992.

Appendix A Explanatory Material

Appendix A is not a part of the recommendations of this NFPA document but is included for informational purposes only. This appendix contains explanatory material, numbered to correspond with the applicable text paragraphs.

A.1.1.2 See NFPA 70, *National Electrical Code*®, for additional information on grounding to prevent shock hazards.

A.1.1.3 For information on the hazards of static electricity in hospital operating rooms and similar areas, see NFPA 99, *Standard for Health Care Facilities.*

A.1.1.4 For information on the hazards of lightning, see NFPA 780, *Standard for the Installation of Lightning Protection Systems.*

A.1.1.5 For information on the hazards of stray electrical currents and induced radio frequency currents, see API RP 2003, *Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents.*

A.1.1.6 For information on the hazards of automotive and marine craft fueling, see NFPA 30A, *Code for Motor Fuel Dispensing Facilities and Repair Garages*, and NFPA 302, *Fire Protection Standard for Pleasure and Commercial Motor Craft.* For information on aircraft refueling, see NFPA 407, *Standard for Aircraft Fuel Servicing.*

A.1.1.7 For information on the hazard of static electricity in clean rooms, see NFPA 318, *Standard for the Protection of Cleanrooms.*

A.3.1.5 Capacitance. The property of a system of conductors and nonconductors that permits the storage of electrically separated charges when potential differences exist between the conductors. For a given potential difference, the higher the capacitance, the greater the amount of charge that can be stored. Quantitatively, it is the ratio of the charge on one of the conductors of a capacitor (there being an equal and opposite charge on the other conductor) to the potential difference between the conductors. The unit of capacitance is the farad. Because the farad is so large a quantity, capacitance is usually reported in microfarads (μF) or picofarads (pF).

1 farad = 10^6 microfarads = 10^{12} picofarads. *(See Table A.3.1.5 for examples.)*

Table A.3.1.5 Examples of Capacitance of Various Items

Item	Capacitance (pF)
Tank car	1000
Automobile	500
Person	100 to 300
Oil/solvent drum	10 to 100
Metal scoop	10 to 20
Needle electrode	1
Dust particle	10^{-7}

Capacitance is the constant of proportionality between the charge and potential difference for a system of conductive bodies.

A.4.3.3.4 MIEs can be determined for pure materials and their mixtures. The actual ignition energy could be higher than the MIE by an order of magnitude or more if the mixture varies significantly from the most easily ignited concentration. For hazard evaluation, the MIE should be considered as the worst case.

A.4.3.8 See Britton, *Avoiding Static Ignition Hazards in Chemical Operations,* for additional information.

A.6.6.2.2 See ANSI Z41, *American National Standard for Personal Protection — Protective Footwear.*

A.6.6.3 See Britton, *Avoiding Static Ignition Hazards in Chemical Operations*, for additional information.

A.6.6.4.2 See Britton, *Avoiding Static Ignition Hazards in Chemical Operations*, for additional information.

A.6.6.4.3 See NFPA 53, *Recommended Practice on Materials, Equipment, and Systems Used in Oxygen-Enriched Atmospheres.*

A.7.2.1 Class I flammable liquids [i.e., those that have flash points of less than 100°F (37.8°C)] can form ignitible vapor–air mixtures under most ambient conditions. Class II and Class III combustible liquids, which have flash points of 100°F (37.8°C) or greater, typically require some degree of preheating before they evolve enough vapor to form an ignitible mixture. Certain liquids of low fire hazard, such as solvent formulations consisting of mostly water, might be classed as combustible liquids, yet they can generate ignitible vapor–air mixtures in closed containers at less than 100°F (37.8°C). Similarly, certain liquids that do not have a flash point could be capable of generating an ignitible vapor–air mixture as a result of degassing or slow decomposition, especially where the vapor space is small compared with the liquid volume.

Errors in Flash Point Testing. The reported flash point of a liquid might not represent the minimum temperature at which a pool of liquid will form an ignitible atmosphere. Typical closed-cup test methods involve downward flame propagation, which is more difficult than upward propagation, and the region where the test flame is introduced is normally fuel-lean relative to the liquid surface. Also, the volume of the test apparatus is too small to allow flame propagation of certain flammable vapors such as halogenated hydrocarbons. Limitations of flash point test methods are discussed in ASTM E 502, *Standard Test Method for Selection and Use of ASTM Standards for the Determination of Flash Point of Chemicals by Closed Cup Methods.* In most cases, closed-cup flash points are lower than open-cup values.

Safety Margin for Use of Flash Point. The temperature of interest in determining the hazard is the temperature at the exposed liquid surface, not that of the bulk liquid, because vapor is in equilibrium with the liquid at the surface. However, the surface temperature is difficult to determine in many instances. While the surface temperature should be considered to the extent possible, most hazard evaluations are, by necessity and practicality, based on bulk temperature. Therefore, a safety factor should be applied where the hazard is assessed using the flash point. For pure liquids in containers, the vapor should be considered potentially ignitible if the liquid temperature is within 4°C of the reported flash point. For mixtures whose composition is less certain, such as hydrocarbon mixtures, the safety factor should be at least 9°C. Where combinations of adverse effects are identified, the safety factors might have to be increased accordingly.

Effect of Bulk Liquid Temperature. The surface temperature of a quiescent liquid in a tank can significantly exceed the temperature of the bulk liquid, due to heat transfer from the unwet upper walls of the tank, which in some cases could be heated by sunlight to as much as 140°F. Because vapor–liquid equilibrium is established at the vapor–liquid interface, this higher surface temperature can result in a vapor concentration that is elevated compared to the concentration based on the bulk liquid temperature. This elevated concentration means that vapor in the tank could be ignitible even if the bulk liquid temperature is less than the reported flash point, which can be a significant hazard during sampling. Vapor vented from large storage tanks could be at a concentration that is only 30 percent to 50 percent of theoretical saturation, based on bulk liquid temperature. This vapor also could be a significant hazard, if tank vapor is assumed to be above the UFL.

Effect of Ambient Pressure. The vapor pressure above a liquid depends only on the temperature at the surface and the time necessary to reach equilibrium. The fraction of the total pressure exerted by a vapor determines the composition of the vapor–air mixture. Thus, when the total pressure is reduced, as could be the case at high altitudes, the vapor concentration in air increases. Because flash points are reported at a pressure of 1 atm (760 mm Hg or 101.3 kPa), an ambient pressure less than this value will lower the actual effective flash point. The flash point correction given in ASTM E 502 is expressed as follows:

$$FP_{corr}\,(°\mathrm{C}) = C + 0.25(101.3 - A)$$

$$FP_{corr}\,(°\mathrm{C}) = C + 0.03(760 - B)$$

$$FP_{corr}\,(°\mathrm{F}) = F + 0.06(760 - B)$$

where:

FP_{corr} = corrected flash point
F = observed flash point (°F)
C = observed flash point (°C)
A = ambient barometric pressure (kPa)
B = ambient barometric pressure (mm Hg)

Effect of Low Concentration of Volatiles. Small concentrations of volatile components in a liquid mixture can accumulate in the vapor space of a container over time, which can reduce the flash point to a temperature below the reported value. This effect can result from off-gassing, chemical reaction, or some other mechanism. An example is bitumen. Similarly, if a tank truck is not cleaned after delivering gasoline and a higher flash point liquid, such as kerosene or diesel fuel, is transferred to it, the residual gasoline will create an ignitible atmosphere both in the truck's tank and possibly in the receiving tank as well. Solids that contain more than 0.2 wt percent flammable solvent need to be evaluated for their potential to form ignitible vapor in containers.

Liquid Mist. If a liquid is dispersed in air in the form of a mist, it could be possible to propagate a flame through the mist, even at temperatures below the liquid's flash point. In such cases, the mist droplets behave like dust particles. The flash point of the liquid is irrelevant when determining combustibility of mists. Even at very low liquid temperatures, frozen liquid droplets can burn in this manner. Ease of ignition and rate of combustion both increase as the droplet size of the mist decreases. Depending on the volatility of the liquid, droplets with a diameter less than 20 to 40 μm typically vaporize and ignite ahead of a flame front, and their overall combustion behavior is similar to that of a vapor. Because mists are usually produced by some form of shear process and these same processes also generate static electricity, it is good practice to avoid splashing and other procedures that generate mist inside equipment.

A.7.2.2 Operating a process at less than the LFL is often safer than operating above the UFL, particularly for tanks and other large vessels. Even if liquid in a tank rapidly generates sufficient vapor for operation above the UFL, flammable mixtures can still be present at tank openings, such as sampling ports, and the flammable range could be traversed inside the tank during start-up or some other operating condition. Often, the atmosphere in the vessel can be inerted, as described in NFPA 69, *Standard on Explosion Prevention Systems.* This technique reduces the oxygen concentration below that required to sustain combustion. Inerting might not be effective near tank openings, especially in cases where additions of solids can entrain air. Also, for storage tanks, the inert gas supply should be capable of compensating for changes in temperature or inbreathing of air during tank emptying.

Vapor Pressure. The vapor pressure can be used together with a measured LFL to estimate the flash point. Usually, the calculated flash point is less than the measured value due to limitations in the flash point test technique. Conversely, only an approximate estimate of the LFL can be made from the flash point. The vapor pressure can be used to replace the "concentration" axis in Figure 7.2.3 with the corresponding temperatures required to generate the concentrations shown in the figure. This method allows one to determine the equilibrium liquid temperature at which vapor ignition is most probable, corresponding to generation of the vapor–air mixture having the lowest ignition energy. For many liquids, this point is approximately halfway between the LFLs and UFLs. For example, benzene generates its lowest MIE vapor–air mixture at about 7°C (4.8 percent benzene vapor in air) and toluene at about 2.6°C (4.1 percent toluene vapor in air). Therefore, for operations conducted at room temperatures, toluene is more prone to ignition from a low energy static electric discharge than is benzene. In closed containers at equilibrium, benzene becomes too rich to burn (the concentration of vapor exceeds its UFL of 8 percent) at temperatures above about 16°C. Conversely, at about 7°C, benzene is more easily ignited than toluene, because the latter will generate a vapor composition not far above its LFL. Some lowest MIE compositions are given in Appendix B.

High Vapor Pressure Liquids. High vapor pressure liquids are defined in API RP 2003, *Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents*, as having a Reid vapor pressure greater than 4.5 psia (31 kPa absolute). At normal handling temperatures, rapid evaporation of these liquids minimizes the duration of a flammable atmosphere above the liquid during loading and the UFL is soon exceeded. However, if there is no initial heel in the tank and the tank is not inerted, the flammable range will be traversed prior to attaining vapor equilibrium. The duration of the ignitible atmosphere is minimal for liquefied gases such as propylene, but could be considerable for certain petroleum distillate fuels. Inerting might be considered when loading high vapor pressure nonconductive liquids to tanks containing air with no liquid heel.

Intermediate Vapor Pressure Liquids. Intermediate vapor pressure liquids are defined in API RP 2003 as having a Reid vapor pressure less than 4.5 psia (31 kPa absolute) and a closed-cup flash point below 100°F (37.8°C). They are most likely to generate ignitible mixtures in vessels at ordinary temperatures. Although graphical methods have been proposed to estimate whether liquids are likely to generate ignitible atmospheres at various temperatures, based on their Reid vapor pressures, such graphs were originally derived for petroleum fuel mixtures and do not always apply to other flammable liquids.

Low Vapor Pressure Liquids. Low vapor pressure liquids are Class II and Class III combustible liquids [i.e., those with closed-cup flash points above 100°F (37.8°C)] and will generate ignitible atmospheres only if handled at elevated temperature, suspended as a mist, or subject to slow vapor evolution. However, static electricity generated during handling could ignite vapors present from previous operations.

A.7.2.4 Preventing an ignitible atmosphere can be accomplished using any of the methods described in NFPA 69, *Standard on*

Explosion Prevention Systems. Of these methods, the most common is to add a suitable inert gas, such as nitrogen, so that the resulting concentration of oxygen is not sufficient to support a flame. A safety factor is usually applied. For most flammable gases and vapors, inerting typically requires reducing the oxygen concentration to about 5 percent by volume.

A.7.3.1 The system of two layers having opposite net charge is referred to as an *electrical double layer.* For conductive liquids such as water, the diffuse layer is only a few molecules thick. But for nonconductive liquids such as light petroleum distillates, the layer could be many millimeters thick. Ionic species present in liquids undergo charge separation at interfaces in a manner that results in one sign of charge being more strongly bound at the contacted surface than the other. This results in a bound layer of liquid close to the contact surface. Farther away from the contact surface is a "diffuse layer" that has a charge of opposite polarity. Any process that shears the liquid, such as pipe flow, moves the diffuse layer downstream with the bulk of the liquid, while the bound layer charge relaxes to the wall, provided the wall is grounded. This process, in effect, allows the diffuse layer to result in charge accumulation in the liquid. When small droplets having dimensions smaller than the thickness of the double layer are formed, the formation of the droplet can pinch off a net charge. This can result in charged sprays and mists for both conductive and nonconductive liquids. The larger the area of the interface, the greater is the rate of charging. Examples of such processes are fine filtration, agitation of two-phase systems such as water and oil, and suspension of powder in liquid.

Streaming Current. The charges that are carried in the bulk of the flowing liquid create a current referred to as a *streaming current.* Although the charge is separated at the wall, flow mixes the charge into the bulk of the liquid and a charge density measured in coulombs per cubic meter can be achieved. Streaming current, in coulombs per second or amperes, is equal to the volume flow rate, in cubic meters per second, multiplied by the liquid charge density, in coulombs per cubic meter.

A.7.3.2 Charge relaxation is characterized by a time constant, which is the time required for a charge to dissipate to e^{-1} (approximately 37 percent) of its original value, assuming that charge relaxation follows exponential decay. This time constant is determined from the following equation:

$$\tau = \frac{\varepsilon\varepsilon_0}{\kappa}$$

where:

τ = time constant

ε = dielectric constant for the liquid

$\varepsilon_0 = 8.854 \times 10^{-12}$, permittivity of free space (farads per meter)

κ = liquid conductivity (picosiemens per meter)

Overall, the time constant provides some indication of a liquid's potential for accumulating a static electric charge. Exponential, or "ohmic," decay has been experimentally confirmed for hydrocarbon liquids having conductivities of 1 pS/m or greater and is described by the following equation:

$$Q_t = Q_0 e^{-t\kappa/\varepsilon\varepsilon_0}$$

where:

Q_t = charge density (coulombs per cubic meter)
Q_0 = initial charge density (coulombs per cubic meter)
e = 2.718, base of natural logarithms
t = time (seconds)
κ = liquid conductivity (picosiemens per meter)
ε = liquid dielectric constant
$\varepsilon_0 = 8.854 \times 10^{-12}$, permittivity of free space (farads per meter)

According to W. M. Bustin (Bustin, W. M., et al, 1964), the rate at which charge is lost depends on the conductivity of the liquid. The lower the conductivity, the slower the relaxation. Liquids with conductivity of less than 1 pS/m relax differently when they are highly charged. The usual relationship described by Ohm's law does not apply. Instead, for nonviscous liquids (i.e., less than 30×10^{-6} m^2/sec), relaxation precedes hyperbolic decay. The Bustin theory of charge relaxation has been experimentally confirmed for low-conductivity hydrocarbon liquids, both in small-scale laboratory experiments and in full-scale tests and is described by the following equation:

$$Q_t = \frac{Q_0}{(1 + \mu Q_0 t/\varepsilon\varepsilon_0)}$$

where:

Q_t = charge density (coulombs per cubic meter)
Q_0 = initial charge density (coulombs per cubic meter)
μ = ion mobility, about 1×10^{-8} m^2/V-sec for charged distillate oil (square meters per volt-second)
t = time (seconds)
$\varepsilon\varepsilon_0$ = electrical permittivity (farads per meter)

The Bustin theory of charge relaxation depends only on the initial charge density, Q_0, and ion mobility, μ. The conductivity of the uncharged liquid is not a factor. In addition, Bustin charge decay theory is not very sensitive to initial charge density when the initial charge density is greater than about 100 microcoulombs per cubic meter.

A.7.3.3 The mechanism of charge generation is highly complex. For flow of liquid in pipes, the charging current depends on the liquid's electrical conductivity and dielectric constant and its viscosity and flow characteristics, which involve factors such as flow velocity, pipe diameter, and surface roughness. For equal flow characteristics, electrical conductivity is the dominant factor. This is most pronounced for low conductivity liquids, due to trace contaminants. Trace contaminants have negligible effect on the liquid's dielectric constant and viscosity, but have a dominant effect on conductivity. Conductive liquids are much less affected by trace contaminants. In many systems, such as long pipes, the charge density reaches a steady state at which the rate of charge generation is balanced by the rate of charge relaxation back to ground.

Classification of Liquids Based on Conductivity. The conductivity of most flammable and combustible liquids varies from about 10^{-2} pS/m to 10^{10} pS/m (i.e., by 12 orders of magnitude). Dielectric constants usually range from 2 to 40 — the higher values being generally exhibited by polar liquids, which also exhibit higher conductivity. Because relaxation behavior is primarily governed by conductivity, conductivity can be used to classify liquids relative to their potential for charge accumulation as nonconductive, semiconductive, and conductive. Because conductivity is so sensitive to purity and temperature, class demarcations can be given only to within an order of magnitude. It should be kept in mind that conductivity under actual conditions could be less than what is measured in the laboratory. *(See Appendix B for conductivity values and relaxation times for some typical liquids.)*

Nonconductive Liquids. Liquids that have relaxation time constants greater than 0.36 seconds (equivalent to a conductivity of less than 50 pS/m for typical hydrocarbons having dielectric constants of about 2) are considered nonconductive. Examples include purified toluene and most low-sulfur diesel oils. They are highly susceptible to variation due to trace contamination. Corona and brush discharges, rather than spark discharges, are observed from charged nonconductive liquids. Because only partial discharge is possible, induction charging from highly charged plastic containers is not a significant hazard. Nonconductive liquids are most prone to accumulate charge in grounded metallic containers. For the purposes of this recommended practice, the criterion of 50 pS/m is not iron-clad; the dielectric constant also plays a role. For example, the dielectric constant of ethyl ether is 4.6 versus 2.3 for benzene. Therefore, the relaxation time constant for ethyl ether at a conductivity of 100 pS/m is approximately the same as that for benzene at a conductivity of 50 pS/m. It is the relaxation time constant, not the conductivity alone, that determines the rate of loss of charge.

Semiconductive Liquids. Liquids that have relaxation time constants ranging from 0.36 sec down to 0.002 sec (equivalent to a conductivity range between 50 and 10^4 pS/m for typical hydrocarbons having dielectric constants of about 2) are considered conductive. Examples include crude oil and butyl acetate. They tend not to accumulate charge, except where charging rates are extremely high or where they are effectively isolated from ground, such as when flowing through a rubber hose or end-of-line "polishing" filters. Spark discharges are possible from the more conductive of these liquids.

Conductive Liquids. Liquids that have relaxation time constants less than 0.002 sec (equivalent to a conductivity greater than 10^4 pS/m for typical hydrocarbons having dielectric constants of about 2) are considered highly conductive. These liquids tend not to accumulate charge except where handling conditions isolate them from ground. Such conditions include complete isolation in the form of a droplet suspended in air, partial isolation by suspension in another liquid, and containment in a plastic or other highly resistive container. Conductive liquids are most prone to induction charging by plastic containers and are sufficiently conductive to lose much of the induced charge in the form of a spark.

Changes in Conductivity Caused by Solidification. Liquids can undergo a sudden and dramatic decrease in conductivity at their freezing points, which in some cases can cause unexpected static electricity hazards. For example, the conductivity of biphenyl decreases by 4 orders of magnitude between the liquid phase (above 69°C) and the solid phase. A static electric ignition was reported when biphenyl at 120°C was loaded into a tank containing a thick layer of solid biphenyl from a previous operation.

Normally, hot biphenyl is conductive enough to rapidly dissipate charge when loaded into a grounded metal tank. But due to the presence of the thick, insulating layer of solid biphenyl, charge was able to accumulate and a brush discharge occurred from the liquid surface to the fill pipe.

A.7.4.1 See Britton, *Avoiding Static Ignition Hazards in Chemical Operations*, for additional information.

Various theoretical and empirical models have been derived expressing either charge density or charging current in terms of flow characteristics, such as pipe diameter and flow velocity. Liquid dielectric and physical properties appear in more complex models. For turbulent flow of a nonconductive liquid through a pipe under conditions where the residence time is long compared with the relaxation time, the charging current, I_s, can be expressed by the following:

$$I_s = N(v^x)(d^y)$$

where:

I_s = charging current
N = constant (characterizing flow conditions, see text)
x = approximately 2
y = approximately 2
v = flow velocity (m/sec)
d = diameter of conduit (m)

Various values for the constants can be found in the literature. For I_s, in amperes, the constant N has been reported to range from 3.75×10^{-6} C-sec/m^4 to 25×10^{-6} C-sec/m^4. The low value corresponds to turbulent flow through a long, smooth pipe, while the high value corresponds to turbulent flow through spiral-wound composite hose. An order of magnitude value for N is 1×10^{-5} C-sec/m^4. While more recent studies suggest that y is equal to 1, it has been most commonly reported that both x and y are approximately equal to 2, so that the charging current is roughly proportional to the square of $(v \times d)$. An important outcome of the studies is that $(v \times d)$ can be used as a means of characterizing the charging current in pipe flow and as a basis for setting flow limits when filling tanks. *(See Sections 7.5 and 7.6.)*

A.7.4.2 All-plastic nonconductive pipe is not recommended for handling nonconductive or semiconductive liquids, except where it can be shown that the advantages outweigh any risks associated with external static electric discharge or leaks from pinholes or where tests have demonstrated that the phenomena will not occur. Grounded, plastic-lined metal pipe does not pose either of these risks directly, but tolerance for liner pinholes should be considered. For example, if the liquid is corrosive to metal piping, gradual loss of metal because of pinholes could lead to unacceptable product contamination and eventual loss of containment. Conversely, minor pinhole damage might be acceptable, if the liner is intended only to minimize product discoloration caused by rust and scale.

Where nonconductive and partly conductive liquids need to be transferred through plastic piping systems, mitigating strategies include the following:

(1) Reducing the rate of charging by decreasing flow velocity
(2) Eliminating or relocating microfilters further upstream
(3) Reducing wall resistivity, possibly to less than 10^8 ohm-m
(4) Increasing the breakdown strength of the pipe wall by increasing the thickness or changing the material of construction
(5) Incorporating an external grounded conductive layer on the piping

Combinations of these strategies can be considered. For example, in many cases, the presence of an external conductive layer on a plastic pipe will not by itself eliminate puncturing of the internal plastic wall, and, if the layer does not provide containment, it will not prevent external leakage.

A.7.4.3 For all-metal conductive hoses, the resistance to ground from any point should normally be 10 ohms or less, except where insulating flanges are used to avoid sparks from stray current. For conductive hoses that contain a continuous bonding element, such as wire or braid, the resistance to ground from any metal connector should normally be 1000 ohms per meter or less, with the same exception being applicable. Resistance to ground through semiconductive hoses whose current-limiting design eliminates a low-resistance bonding element and resistance to ground through insulating flanges should be between 10^3 ohms/m and 10^5 ohms/m. In either case, the total resistance to ground from a metal hose connector should not exceed 10^6 ohms.

While a resistance to ground of less than 10^6 ohms will prevent accumulation of static electric charge in most cases, if periodic testing reveals a significant increase in the as-installed resistance, this could be the result of corrosion or other damage that could lead to sudden loss of continuity. The hose or insulating flange, or both, should be inspected to determine the need for replacement. Where conductive hoses have double spirals, one for bonding and the other for mechanical strength, continuity between the end connectors only confirms the continuity of one spiral. A fire was reported during draining of toluene from a tank vehicle through such a hose. It was found that the inner spiral was not only broken but was not designed to be bonded to the end connectors. For handling nonconductive liquids, one option is to use a hose with a semiconductive or conductive liner, so that a broken inner spiral cannot become isolated from ground and form a spark gap. Ideally, the inner spiral should be separately bonded to the end connectors.

It is especially important to ensure continuity with end connectors (or nozzles) where a hose is used in an ignitible atmosphere. In general, it is safer to use a properly designed fixed fill system, such as a dip pipe arrangement, for filling tank vehicles, rather than to use a hose.

Utility Hoses. Where used in flammable atmospheres, such as inside tanks, utility hoses should be conductive or semiconductive. In particular, all metal connectors and nozzles should be grounded. Ungrounded hose connectors on nonconductive hose can become charged by a variety of means, such as by inserting a nitrogen hose into a tank containing charged liquid or mist, by rubbing, or by steam impact. While clean and dry gases do not generate charge, a nonconductive hose will become highly charged by the flow of steam.

A.7.5.2.1(c) See API 2003, *Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents*, for further information.

A.7.7 See API Publication 2219, *Safe Operation of Vacuum Trucks in the Petroleum Service*, for general recommendations.

A.7.10.2 See NFPA 69, *Standard on Explosion Prevention Systems*, for additional information.

A.7.13.7 See NFPA 326, *Standard for the Safeguarding of Tanks and Containers for Entry, Cleaning, or Repair.*

A.7.14 If used for flammable liquid spills, which could involve a second phase such as spill control granules or debris, wet-dry vacuum cleaners pose a number of problems, including the following:

(1) Generation of static electricity
(2) Electrical classification of powered equipment
(3) Chemical compatibility
(4) Industrial hygiene (relative to the exhaust from the vacuum cleaner)

Commercial machines for Class I, Group D, and Class II, Groups E, F, and G atmospheres are typically air-operated via a venturi, so they contain no electrical power. Air supply and liquid recovery hoses should be conductive and constructed of semiconductive fabric. Filters are also semiconductive or conductive. The design is such that all parts are continuously bonded and grounded. Normally ground continuity at prescribed checkpoints is established before each use. Floats or similar mechanisms are employed to shut off suction once the recovery tank has reached capacity level. Additional precautions might be needed to avoid overflow via siphoning (if the recovery hose is completely submerged in liquid) or when defoaming agents are not used. For flammable liquid spills in particular, measures should be taken, including training and personnel grounding, to ensure personnel are not a source of ignition.

A.8.2.4 The MIE of a dust cloud is determined using a sample that is representative of the dust in a process. The equipment and procedures used over the years have been many and varied. Therefore, MIE data might not be comparable from one data set to the next. Furthermore, the conditions under which laboratory data are acquired can be different than that of the process being examined. For these reasons, comparisons of MIE data are sometimes qualitative rather than quantitative. Nevertheless, comparisons can be quite useful.

The MIE of a dust decreases with decreasing particle size and with increasing temperature. The MIE could increase with increasing moisture content of the dust. The MIE of a dust varies little with the humidity of the supporting atmosphere, excluding problems with hygroscopic dusts. The factors affecting MIE should be considered in a hazards analysis of a process.

A.8.7 Some flexible hoses can be cut to length and put into service by simply slipping them over a pipe with a hose clamp. It is important that the spiral wires be in good metal-to-metal contact with the pipes in order to maintain a proper ground of the spiral. This contact can be done by stripping the spiral and bending it under the hose next to the pipe and under the clamp. In cases where hoses with metal spirals are connected to plastic pipes, the spirals should be independently grounded.

The reason for discouraging the use of hose with more than one spiral is that, if one of the spiral wires is broken in such a way that it is disconnected from ground, it can become a source of spark gap ignition.

A.8.10 See Britton, *Avoiding Static Ignition Hazards in Chemical Operations*, for additional information.

A.8.11 See Britton, *Avoiding Static Ignition Hazards in Chemical Operations*, for additional information.

A.9.3.2 See NFPA 33, *Standard for Spray Application Using Flammable or Combustible Materials*, for further information.

A.9.4.2.1 Investigations into the static electric hazard in grain elevators have shown that danger exists when the voltage reaches 30,000 volts on the belt. These studies also show that low relative humidity is an important factor in that it allows voltages to increase very rapidly at temperatures below freezing.

A.9.4.2.2 The surface resistivity of a grain conveyor belt affects its ability to accumulate a charge. Tests have shown that belts with a resistance of 10^6 ohms to 10^8 ohms are conductive enough to prevent significant accumulation of charge. According to the draft standard *Safety of Machinery — Electrotechnical Aspects*, published by the European Committee for Electrotechnical Standardization (CENELEC), a belt is considered to be sufficiently conductive if the surface resistance is less than 3×10^8 ohms.

A.9.4.3 According to the draft standard *Safety of Machinery — Electrotechnical Aspects*, published by the European Committee for Electrotechnical Standardization (CENELEC), V belts and similar transmission belts are considered to be sufficiently conductive if the following criterion is met:

$$R \times B < 10^5 \text{ohm-m}$$

where:

R = resistance measured at the inner side of the mounted transmission belt between an electrode halfway between the two pulleys and ground
B = width of a flat belt or twice the depth of the side face of a V belt

For belts constructed of different materials, the belt is considered to be sufficiently conductive if the resistance across the belt does not exceed 10^9 ohms, measured at 23°C and 50 percent relative humidity.

Appendix B Physical Characteristics of Materials

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

B.1 Combustibility Parameters of Gases and Vapors. Table B.1 lists typical gases and vapors and the lowest value of their minimum ignition energies in millijoules; the stoichiometric composition, expressed as percent by volume in air (or other oxidant); and the flammable limits, also expressed as percent by volume in air (or other oxidant). (The data are taken from Britton, L. G., "Using Material Data in Static Hazard Assessment," *Plant/Operations Progress*, American Institute of Chemical Engineers, New York, NY, Vol. 11, No. 2, April, 1992, pp. 56–70.

Table B.1 Combustibility Parameters of Gases and Vapors

Gas or Vapor (in air at standard temperature and pressure, unless otherwise noted)	Lowest Minimum Ignition Energy (mJ)	Stoichiometric Mixture (% by volume)	Flammable Limits (% by volume)
acetaldehyde	0.37	7.73	4.0–57.0
acetone	1.15 @ 4.5%	4.97	2.6–12.8
acetylene	0.017 @ 8.5%	7.72	2.5–100
acetylene in oxygen	0.0002 @ 40%	—	—
acrolein	0.13	5.64	2.8–31
acrylonitrile	0.16 @ 9.0%	5.29	3.0–17.0
allyl chloride	0.77	—	2.9–11.1
ammonia	680	21.8	15–28
benzene	0.2 @ 4.7%	2.72	1.3–8.0
1,3-butadiene	0.13 @ 5.2%	3.67	2.0–12
butane	0.25 @ 4.7%	3.12	1.6–8.4
n-butyl chloride	1.24	3.37	1.8–10.1
carbon disulfide	0.009 @ 7.8%	6.53	1.0–50.0
cyclohexane	0.22 @ 3.8%	2.27	1.3–7.8
cyclopentadiene	0.67	—	—
cyclopentane	0.54	2.71	1.5 – nd
cyclopropane	0.17 @ 6.3%	4.44	2.4–10.4
dichlorosilane	0.015	17.36	4.7–96
diethyl ether	0.19 @ 5.1%	3.37	1.85–36.5
diethyl ether in oxygen	0.0012	—	2.0–82
diisobutylene	0.96	—	1.1–6.0
diisopropyl ether	1.14	—	1.4–7.9
dimethoxymethane	0.42	—	2.2–13.8
2,2-dimethylbutane	0.25 @ 3.4%	2.16	1.2–7.0
dimethyl ether	0.29	—	3.4–27.0
2,2-dimethyl propane	1.57	—	1.4–7.5

(Sheet 1 of 2)

Table B.1 Combustibility Parameters of Gases and Vapors *(Continued)*

Gas or Vapor (in air at standard temperature and pressure, unless otherwise noted)	Lowest Minimum Ignition Energy (mJ)	Stoichiometric Mixture (% by volume)	Flammable Limits (% by volume)
dimethyl sulfide	0.48	—	2.2–19.7
di-t-butyl peroxide	0.41	—	—
ethane	0.24 @ 6.5%	5.64	3.0–12.5
ethane in oxygen	0.0019	—	3.0–66
ethyl acetate	0.46 @ 5.2%	4.02	2.0–11.5
ethylamine	2.4	5.28	3.5–14.0
ethylene	0.07	—	2.7–36.0
ethylene in oxygen	0.0009	—	3.0–80
ethyleneimine	0.48	—	3.6–46
ethylene oxide	0.065 @ 10.8%	7.72	3.0–100
furan	0.22	4.44	2.3–14.3
heptane	0.24 @ 3.4%	1.87	1.05–6.7
hexane	0.24 @ 3.8%	2.16	1.1–7.5
hydrogen	0.016 @ 28%	29.5	4.0–75
hydrogen in oxygen	0.0012	—	4.0–94
hydrogen sulfide	0.068	—	4.0–44
isooctane	1.35	—	0.95–6.0
isopentane	0.21 @ 3.8%	—	1.4–7.6
isopropyl alcohol	0.65	4.44	2.0–12.7
isopropyl chloride	1.08	—	2.8–10.7
isopropylamine	2.0	—	—
isopropyl mercaptan	0.53	—	—
methane	0.21 @ 8.5%	9.47	5.0–15.0
methane in oxygen	0.0027	—	5.1–61
methanol	0.14 @ 14.7%	12.24	6.0–36.0
methylacetylene	0.11 @ 6.5%	—	1.7 – nd
methylene chloride	>1000	—	14–22
methyl butane	<0.25	—	1.4–7.6
methyl cyclohexane	0.27 @ 3.5%	—	1.2–6.7
methyl ethyl ketone	0.53 @ 5.3%	3.66	2.0–12.0
methyl formate	0.4	—	4.5–23
n-pentane	0.28 @ 3.3%	2.55	1.5–7.8
2-pentane	0.18 @ 4.4%	—	—
propane	0.25 @ 5.2%	4.02	2.1–9.5
propane in oxygen	0.0021	—	—
propionaldehyde	0.32	—	2.6–17
n-propyl chloride	1.08	—	2.6–11.1
propylene	0.28	—	2.0–11.0
propylene oxide	0.13 @ 7.5%	—	2.3–36.0
tetrahydrofuran	0.54	—	2.0–11.8
tetrahydropyran	0.22 @ 4.7%	—	—
thiophene	0.39	—	—
toluene	0.24 @ 4.1%	2.27	1.27–7.0
trichlorosilane	0.017	—	7.0–83
triethylamine	0.75	2.10	—
2,2,3-trimethyl butane	1.0	—	—
vinyl acetate	0.7	4.45	2.6–13.4
vinyl acetylene	0.082	—	1.7–100
xylene	0.2	1.96	1.0–7.0

(Sheet 2 of 2)

nd = not determined.

B.2 Static Electric Characteristics of Liquids. Table B.2 lists typical flammable and combustible liquids and their conductivities, dielectric constants, and relaxation time constants. (The data are taken from Britton, L. G., "Using Material Data in Static Hazard Assessment," *Plant/Operations Progress*, American Institute of Chemical Engineers, New York, NY, Vol. 11, No. 2, April, 1992, pp. 56–70.)

Table B.2 Static Electric Characteristics of Liquids

Liquid	Conductivity (pS/m)	Dielectric Constant	Relaxation Time Constant (sec)
Conductive Liquids: Conductivity >10^4 pS/m			
acetaldehyde (15°C)	1.7×10^8	21.1	1.1×10^{-6}
acetamide	8.8×107	59	5.9×10^{-6}
acetic acid (0°C)	5×10^5	6.15	1.1×10^{-4}
acetic acid (25°C)	1.12×10^6	6.15	4.9×10^{-5}
acetic anhydride (25°C)	4.8×10^7	n/a	n/a
acetone (25°C)	6×10^6	20.7	3×10^{-5}
acetonitrile (20°C)	7×10^8	37.5	5×10^{-7}
acetophenone (25°C)	3.1×10^5	17.39	5.0×10^{-4}
acetyl bromide (25°C)	2.4×10^8	n/a	n/a
acetyl chloride (25°C)	4×10^7	n/a	n/a
acrolein	1.55×10^7	n/a	n/a
acrylonitrile	7×10^5	38	4.8×10^{-4}
allyl alcohol (25°C)	7×10^8	n/a	n/a
aminoethyl-ethanolamine	$> 1 \times 10^6$	n/a	n/a
n-aminoethyl piperazine	2.4×10^5	n/a	n/a
ammonia (–79°C)	1.3×10^7	n/a	n/a
iso-amyl alcohol	1.4×10^5	14.7	9.3×10^{-4}
aniline (25°C)	2.4×10^6	6.89	2.5×10^{-5}
anthracene (25°C)	3×10^4	n/a	n/a
arsenic tribromide (25°C)	1.5×10^8	n/a	n/a
arsenic trichloride (25°C)	1.2×10^8	n/a	n/a
benzaldehyde (25°C)	1.5×10^7	n/a	n/a
benzoic acid (125°C)	3×10^5	n/a	n/a
benzonitrile (25°C)	5×10^6	25.2	4.5×10^{-5}
benzyl alcohol (25°C)	1.8×10^8	n/a	n/a
benzylamine (25°C)	$< 1.7 \times 10^6$	n/a	n/a
benzyl benzoate (25°C)	$< 1 \times 10^5$	n/a	n/a
benzyl cyanide	$< 5 \times 10^6$	18.7	$> 3.3 \times 10^{-5}$
biphenyl (liquid above 120°C)	$> 1 \times 10^4$	n/a	n/a
bromoform (25°C)	$< 2 \times 10^6$	4.39	$> 1.9 \times 10^{-5}$
iso-butyl alcohol	9.12×10^5	17.51	1.7×10^{-4}
sec-butyl alcohol	$< 1 \times 10^7$	16.56	$> 1.5 \times 10^{-5}$
t-butyl alcohol	2.66×10^6	12.47	4.2×10^{-5}
iso-butyl chloride	1×10^4	6.49	5.7×10^{-3}
sec-butyl chloride	1×10^4	7.09	6.3×10^{-3}
capronitrile (25°C)	3.7×10^8	n/a	n/a
m-chloroaniline (25°C)	5×10^6	n/a	n/a
chlorohydrin (25°C)	5×10^7	n/a	n/a
m-cresol	1.397×10^6	11.8	7.5×10^{-5}
o-cresol	1.27×10^5	11.5	8.0×10^{-4}
p-cresol	1.378×10^6	9.91	6.4×10^{-5}
cyanogen	$< 7 \times 10^5$	n/a	n/a
cyclohexanone	5×10^5	n/a	n/a

(Sheet 1 of 5)

Table B.2 Static Electric Characteristics of Liquids ***(Continued)***

Liquid	Conductivity (pS/m)	Dielectric Constant	Relaxation Time Constant (sec)
cymene (25°C)	$< 2 \times 10^6$	n/a	n/a
dibutyl-o-phthalate	1.8×10^5	6.436	3.2×10^{-4}
dichloroacetic acid (25°C)	7×10^6	n/a	n/a
cis-dichloroethylene	8.5×10^5	9.20	9.6×10^{-5}
dichlorohydrin (25°C)	1.2×10^9	n/a	n/a
diethylamine (–33.5°C)	2.2×10^5	n/a	n/a
diethyl carbonate (25°C)	1.7×10^6	2.82	1.5×10^{-5}
diethylene glycol	5.86×10^7	31.69	4.8×10^{-6}
diethylenetriamine	$> 1 \times 10^6$	n/a	n/a
diethyl oxalate (25°C)	7.6×10^7	n/a	n/a
diethyl sulfate (25°C)	2.6×10^7	n/a	n/a
dimethyl acetamide	1.1×10^7	n/a	n/a
dimethyl formamide	6×10^6	36.71	5.4×10^{-5}
dimethyl sulfate (0°C)	1.6×10^7	n/a	n/a
dimethyl sulfoxide	2×10^5	46.68	2.1×10^{-3}
diphenyl oxide	$< 1.7 \times 10^6$	4.22	$> 2.2 \times 10^{-5}$
epichlorohydrin (25°C)	3.4×10^6	22.6	5.9×10^{-5}
ethanolamine	1.1×10^9	37.72	3.0×10^{-7}
ethylacetate (25°C)	4.6×10^4	6.02	1.2×10^{-3}
ethyl acetoacetate (25°C)	4×10^6	15.7	3.5×10^{-5}
ethyl acrylate	3.35×10^5	n/a	n/a
ethyl alcohol (25°C)	1.35×10^5	24.55	1.6×10^{-3}
ethylamine (0°C)	4×10^7	n/a	n/a
ethyl benzoate (25°C)	$< 1 \times 10^5$	6.02	$> 5.3 \times 10^{-4}$
ethyl bromide (25°C)	$< 2 \times 10^6$	9.39	$> 4.2 \times 10^{-5}$
ethyl chloride	$< 3 \times 10^5$	9.45	$> 2.8 \times 10^{-4}$
ethyl cyanoacetate	6.9×10^7	26.7	3.4×10^{-6}
ethylene carbonate	$< 1 \times 10^7$	89.6	$> 7.9 \times 10^{-5}$
ethylenediamine	9×10^6	12.9	1.3×10^{-5}
ethylene dibromide (25°C)	$< 2 \times 10^4$	4.78	$> 2.1 \times 10^{-3}$
ethylene glycol	1.16×10^8	37.7	2.9×10^{-6}
ethylene glycol monobutyl ether	4.32×10^7	9.30	1.9×10^{-6}
ethylene glycol monoethyl ether	9.3×10^6	29.6	2.8×10^{-5}
ethylene glycol monomethyl ether	1.09×10^8	16.93	1.4×10^{-6}
ethyleneimene	8×10^8	18.3	2.0×10^{-7}
ethylene oxide	4×10^6	12.7	2.8×10^{-5}
ethyl formate	1.45×10^5	7.16	4.4×10^{-4}
ethylidene chloride	2.0×10^5	10.0	4.4×10^{-4}
ethyl isothiocyanate (25°C)	1.26×10^7	n/a	n/a
ethyl lactate	1.0×10^8	13.1	1.2×10^{-6}
ethyl nitrate (25°C)	5.3×10^7	n/a	n/a
ethyl oxalate	7.12×10^7	n/a	n/a
ethyl propionate	8.33×10^{10}	5.65	6×10^{-10}
ethyl thiocyanate (25°C)	1.2×10^8	n/a	n/a
eugenol (25°C)	$< 1.7 \times 10^6$	n/a	n/a
formamide (25°C)	4×10^8	111.0	2×10^{-6}
formic acid (25°C)	6.4×10^9	58.5	8.1×10^{-8}
furfural (25°C)	1.5×10^8	n/a	n/a
glycerol (25°C)	6.4×10^6	42.5	5.9×10^{-5}

(Sheet 2 of 5)

Table B.2 Static Electric Characteristics of Liquids ***(Continued)***

Liquid	Conductivity (pS/m)	Dielectric Constant	Relaxation Time Constant (sec)
guaiacol (25°C)	2.8×10^{7}	n/a	n/a
hydrogen bromide (–80°C)	8×10^{5}	n/a	n/a
hydrogen chloride (–96°C)	1×10^{6}	n/a	n/a
hydrogen cyanide (0°C)	3.3×10^{8}	n/a	n/a
hydrogen iodide (at boiling point)	2×10^{7}	n/a	n/a
iodine (110°C)	1.3×10^{4}	n/a	n/a
mercury (0°C)	1.063×10^{18}	n/a	n/a
methoxy triglycol	$> 1 \times 10^{6}$	n/a	n/a
methyl acetamide	2×10^{7}	191.3	8.5×10^{-5}
methyl acetate (25°C)	3.4×10^{8}	6.68	1.7×10^{-7}
methyl alcohol (18°C)	4.4×10^{7}	32.70	6.6×10^{-6}
methyl cyanoacetate	4.49×10^{7}	29.30	5.8×10^{-6}
methyl ethyl ketone (25°C)	1×10^{7}	18.51	1.6×10^{-5}
methyl formamide	8×10^{7}	182.4	2.0×10^{-5}
methyl formate	1.92×10^{8}	8.5	3.9×10^{-7}
methyl iodide (25°C)	$< 2 \times 10^{6}$	n/a	n/a
methyl isobutyl ketone	$< 5.2 \times 10^{6}$	13.11	$> 2.2 \times 10^{-5}$
methyl nitrate (25°C)	4.5×10^{8}	n/a	n/a
n-methyl-2-pyrolidone	2×10^{6}	32.0	1.4×10^{-4}
methyl thiocyanate (25°C)	1.5×10^{8}	n/a	n/a
naphthalene (82°C)	4×10^{4}	n/a	n/a
nitrobenzene (0°C)	5×10^{5}	34.82	6.2×10^{-4}
nitroethane	5×10^{7}	28.06	5.0×10^{-6}
nitromethane (18°C)	6×10^{7}	35.87	5.3×10^{-6}
1-nitropropane	3.3×10^{7}	23.24	6.2×10^{-6}
2-nitropropane	5×10^{7}	25.52	4.5×10^{-6}
nitrotoluene (25°C) (ortho or meta)	$< 2 \times 10^{7}$	n/a	n/a
octyl alcohol	1.39×10^{7}	10.34	6.9×10^{-6}
phenetole (25°C)	$< 1.7 \times 10^{6}$	n/a	n/a
phenol	1×10^{6}	9.78	8.7×10^{-5}
phenyl isothiocyante (25°C)	1.4×10^{8}	n/a	n/a
phosgene (25°C)	7×10^{5}	n/a	n/a
phosphorus (25°C)	4×10^{8}	n/a	n/a
phosphorus oxychloride (25°C)	2.2×10^{8}	n/a	n/a
pinene (23°C)	$< 2 \times 10^{4}$	n/a	n/a
piperidine (25°C)	$< 2 \times 10^{7}$	n/a	n/a
propionaldehyde (25°C)	8.5×10^{7}	18.5	1.9×10^{-6}
propionic acid (25°C)	$< 1 \times 10^{5}$	3.44	$> 3.0 \times 10^{-4}$
propionitrile	8.51×10^{6}	27.2	2.8×10^{-5}
propyl acetate (i- or n-)	$1 - 6 \times 10^{4}$	6.002	n/a
n-propyl alcohol (25°C)	2×10^{6}	20.33	9×10^{-5}
iso-propyl alcohol (25°C)	3.5×10^{8}	19.92	5×10^{-7}
propyl formate	5.5×10^{9}	7.72	1.2×10^{-8}
pyridine (18°C)	5.3×10^{6}	12.4	2.1×10^{-5}
quinoline (25°C)	2.2×10^{6}	9.0	3.6×10^{-5}
salicylaldehyde (25°C)	1.6×10^{7}	13.9	7.5×10^{-6}
succinonitrile	5.64×10^{10}	56.5	8.9×10^{-9}

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