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Recommended Practice on

Static Electricity

NFPA No. 77–1966

This Manual on Static Electricity was prepared by the NFPA Committee on Static Electricity listed below. It was adopted by the National Fire Protection Association at its 1966 Annual Meeting, held May 16-20, in Chicago, Illinois. The 1961 edition is a complete revision of the previous 1950 edition of the NFPA publication on this subject. This 1966 edition is a clarification of several concepts, an addition to aviation static hazards, and the improvement of several weak paragraphs.

History

NFPA committee activity in this field was initiated in 1936 and a progress report was presented to the Association in 1937. A revised text was tentatively adopted in 1941 and, with further revisions, was finally adopted in 1946. Amendments to the 1946 text were adopted by the Association in 1950. This edition is a complete rewrite of these earlier efforts to explain the generation and accumulation of static, dissipation techniques, and methods of protecting against the hazards of static electrical discharges when handling various materials and in various industrial and commercial processes and equipment. Chapter 9 gives information on static detectors and Appendix A is a glossary of the terms used in the text.

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CHAPTER 1. GENERAL

110. Purpose

1110. The purpose of this recommended practice is to assist in reducing the fire hazard of static electricity by presenting a discussion of the nature and origin of static charges, the general methods of mitigation and recommendations in certain specific operations for its dissipation.

1120. Static electricity is often the ignition source for an ignitible mixture, an operating problem in industry or an annoyance to some individuals.

120. Scope

1210. This publication covers methods for the control of static electricity for the purpose of eliminating or mitigating its fire hazard, except as provided in paragraph 1230 below.

1220. Chapters 5 through 8 cover the common commercial and industrial operations where the presence of static is a hazard. Static is generated in many other circumstances where its accumulation does not constitute a direct fire or explosion hazard. Some of these occurrences may be mentioned in passing but they are not the primary concern of this publication.

1230. The prevention and control of static electricity in hospital operating rooms or in areas where flammable anesthetics are administered are not covered by this publication but are covered in the Code for Flammable Anesthetics, NFPA No. 56.

1240. Lightning is not covered by this publication but is covered in the Lightning Protection Code, NFPA No. 78.

130. Definitions (See also Appendix A)

1310. IGNITIBLE MIXTURE shall mean a vapor-air, gas-air, dust-air mixture or combinations of these mixtures which can be ignited by a static spark.

1320. STATIC SPARK shall mean an impulsive discharge of electricity across a gap between two points not in contact.

1330. BONDING and GROUNDING are defined in Chapter 3 as the act or process of applying or affixing a bond or ground connection between two objects.

1340. The words BONDED or GROUNDED, as they are used in the text, must be understood to mean either that a bond or ground as defined has been deliberately applied, or that an electrically conductive path having a resistance adequately low for the intended purpose (usually 10^6 ohms or less) is inherently present by the nature of the installation.

140. Introduction

1410. The term "static electricity," as used in this publication, shall mean electrification of materials through physical contact and separation, and the various effects that result from the positive and negative charges so formed — particularly where they constitute a fire or explosion hazard. The generation of static electricity cannot be prevented, absolutely, because its intrinsic origins are present at every interface.

1420. The development of electrical charges may not be in itself a potential fire or explosion hazard. There must be a discharge or sudden recombination of separated positive and negative charges. In order for static to be a source of ignition, four conditions must be fulfilled:

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

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

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

d. The spark must occur in an ignitible mixture.

1430. The accumulation of static charges may be prevented under many circumstances by grounding or bonding, by humidification, or by ionization. These means and their functions will be discussed in Chapter 3.

1440. Common sources of static electricity include:

a. Pulverized materials passing through chutes or pneumatic conveyors,

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

c. Nonconductive power or conveyor belts in motion,

d. Moving vehicles,

e. Motions of all sorts that involve changes in relative position of contacting surfaces, usually of dissimilar substances, liquid or solid, one or both of which usually must be a poor conductor of electricity.

1450. The object of most static-corrective measures is to provide a means whereby charges separated by whatever cause may recombine harmlessly before sparking potentials are attained.

1460. If hazardous static conditions cannot be avoided in certain operations, means must be taken to assure that there are no ignitible mixtures at points where sparks may occur.

CHAPTER 2. GENERATION AND ACCUMULATION OF STATIC ELECTRICITY

210. General

2110. To the average person the words "static electricity" may mean either a noise in the radio receiver which interferes with good reception or the electric shock experienced when touching a metal object after walking across a carpeted floor or sliding across the plastic seat cover in an automobile. Some people also have experienced mysterious crackling noises and a tendency for some of their clothing to cling or stick tightly together when wool, silk, or synthetic fiber garments are worn. Nearly everyone recognizes that these phenomena occur mainly when the atmosphere is very dry. To most people they are simply an annoyance.

2120. The word "electricity" is derived from the ancient Greek word "elektron" — meaning amber — for it was with this substance that the phenomenon of electrification was first observed. For centuries "electricity" had no other meaning than the property exhibited by some substances, after being rubbed with a material like silk or wool, of being able to attract or repel lightweight objects. Stronger electrification accompanied by luminous effects and small sparks was first observed about 300 years ago by von Guericke. In comparatively recent times, when the properties of flowing electricity were discovered, the word "static" came into use as a means of distinguishing the old from the new. The implication that such electricity is always at rest is erroneous; it is when it ceases to rest that it causes the most concern.

2130. For the sake of simplicity, one may imagine electricity to be a weightless and indestructible fluid which can move freely through some substances, such as metals, that are called "conductors," but can flow with difficulty or not at all through or over the surface of a class of substances called "nonconductors" or "insulators." This latter group includes: gases, glass, rubber, amber, resin, sulfur, paraffin, and most dry petroleum oils. When electricity is present on the surface of a nonconductive body, where it is trapped or prevented from escaping, it is called *static* electricity. Electricity on a conducting body which is in contact only with nonconductors is also prevented from escaping and is therefore nonmobile or "static." In either case, the body on which this electricity is evident is said to be "charged."

2140. The charge may be either positive (+) or negative (−). At one time it was thought that the two charges were two kinds of electricity and that in a neutral (uncharged) body they were present in exactly equal amounts. Now it is known that there is actually only one kind of electricity, although it is described by many adjectives. It is manifested when some force has abnormally separated a few of its positive and negative constituents. These entities are components of all atoms, the outer electrons (−) and the inner, nuclear, protons (+). Curiously, a surface that has an excess or deficiency of one electron in every 100,000 atoms is very strongly charged.

2150. It is true, however, that in a neutral or uncharged body the two entities are present in exactly equal amounts. Work is required to separate positive and negative charges. Electricity, therefore, is sometimes referred to as a form of energy produced by expenditure of energy in some other form, such as, mechanical, chemical, or thermal. Likewise, when electrical energy (a better term) is expended, its equivalent appears in one or the other of these other forms.

2160. Electrons are free to move from one molecule to another in conductors but the proton, in the nucleus of the atom, cannot move appreciably unless the atom moves. Therefore, in solids, only the electrons are mobile; in gases and liquids both are free to move.

2170. The stable structure of the atom shows that unlike charges attract; conversely like charges repel. It follows that a separated charge will be self-repellent and will reside only on the surface of a charged body. If the body were a perfect insulator or perfectly insulated, the charge would remain indefinitely. However, there are no perfect insulators and isolated charges soon leak away to join their counterparts and thus bring about neutralization, the normal state (also see Article 330).

2180. Static electricity then is the set of phenomena associated with the appearance of an electric charge on the surface of an insulator or insulated conductive body. It is "generated" usually by the expenditure of mechanical work, although we must remember that in this sense generated means "liberated" or made alive — electricity cannot be created. Somewhere, possibly "grounded" but as close as conditions will allow there will be an exactly equal opposite charge — its counterpart. This concept is extremely important.

220. Generation

2210. When two bodies, particularly of unlike materials, are brought into intimate contact, there is likely to be a redistribution of electrons across the interface, and an attractive force is established as equilibrium is achieved. When the bodies are separated, work must be done in opposition to these attractive forces. The expended energy reappears as an increase in electrical tension or voltage between the two surfaces. If a conductive path is available, the charges thus separated will reunite immediately. If no such path is available, as would be the case with insulators, the potential increase with separation may easily reach values of several thousand volts.

2220. Single spark discharges from highly charged insulators rarely deplete enough surface electrification to give sparks with energy sufficient to produce ignition. Thus nonconductors, the bodies most directly involved in charge separation, are usually not directly responsible for fires and explosions. An exception is described in Section 2320. Sparks from insulated conductors, on the other hand, usually drain off the entire charge.

2230. Like charges repel each other and unlike charges attract because of forces resident in the electrical fields that surround them. These forces have a strong influence on nearby objects. If the neighboring object is a conductor it will experience a separation of charges by induction. Its repelled charge is free to give or receive electrons as the case may be; if another conductor is brought near, the transfer may occur through the agency of a spark, very often an energetic spark.

2240. When the inducing charge is moved away from the insulated conductor, there follows a reversed sequence of events, and sparks may result. Thus in many situations, induced charges are far more dangerous than the initially separated ones upon which they are dependent.

2250. If the object close to the highly charged nonconductor is itself a nonconductor, it will be polarized, that is, its constituent molecules will be oriented to some degree in the direction of the lines of force since their electrons have no true migratory freedom. Because of their polarizable nature, insulators and nonconductors are often called dielectrics. Their presence as separating media enhance the accumulation of charge.

230. Ignition Energy

2310. The ability of a spark to produce ignition is governed largely by its energy, which will be some fraction of the total stored energy. Stored energy may be calculated conveniently by means of the formula $\frac{1}{2}CV^2 \times 10^{-9}$ where V is the potential in volts and C is the capacitance in micro-microfarads and the energy is in millijoules or thousandths of a watt-second.

2311. Tests have shown that saturated hydrocarbon gases and vapors require about 0.25 millijoule of stored energy for spark ignition of optimum mixtures with air. It has been shown further that static sparks arising from potential differences of less than 1500 volts are unlikely to be hazardous in these mixtures because of the short gap and heat loss to the terminals. For these minima the capacitance would be $C = \frac{0.5}{V^2} \times 10^9$ or 222 micromicrofarads.

2312. Thus a spark from a charged conductor the size of a large man might be hazardous if the voltage was a little more than 1500 volts and the spark occurred between small electrodes. Five thousand volts would be dangerous if the capacitance was 20 micromicrofarads or more. For assurance of safety with a 10,000-volt spark in an explosive hydrocarbon-air mixture, the capacitance of the charged conductor would have to be noticeably less than $\frac{0.5}{V^2} \times 10^9 = 5$ micromicrofarads: an isolated object the size of a baseball charged to a potential of 10,000 volts could be regarded as hazardous with spark electrodes of almost any shape. On this basis, a 20,000-volt spark would require a storage capacitance of 1¼ micromicrofarads or a charged electrode about the size of a large marble or a 20-penny nail. The spark in air would be at least ¼ in. long.

2313. However, as sparks become considerably longer than the quenching distance (about 1/16 in. to 3/32 in. for the most easily ignited hydrocarbon-air mixtures), the required total energy increases somewhat in proportion to the excess of spark length over the diameter of the necessary critical flame volume. This in turn may require somewhat greater capacitance than indicated above.

2320. When some portion of an extensive nonconductive surface, such as an oil surface, acquires a charge density of 3×10^{-9} coulombs per square centimeter, the potential gradient there will exceed the dielectric strength of air (about 30,000 volts per cm.) and small brush discharges or corona may appear. These serve to make the region conductive and, if the charging process is adequate, a subsequent spark from this conductive surface area may have enough energy to ignite a flammable vapor-air mixture.

2330. Experiments at atmospheric pressure with plane electrodes have shown that the spark breakdown voltage has a minimum value at a critical short gap distance. This minimum sparking potential (about 350 volts) is often cited as a hazard threshold. This voltage will break down a gap no more than 0.0005 in. long. If it were possible to construct needle electrodes that abstracted no heat from the gap, and consequently produced no flame-quenching effect, ignition of a surrounding mixture by a natural 350-volt accumulation of static electricity could still be regarded as a practical impossibility.

2331. Energy storage of 0.25-millijoule at 350 volts would require a capacitance of approximately 4,000 micromicrofarads (0.004 mfd). In order to accumulate this low-voltage minimum-energy charge on the surface of a conductor suspended, for example, in the center of a 3,500,000-gallon petroleum tank, the conductor (charge collector) would have to be much larger than a six-room house.

2340. These are the approximate sizes of highly insulated charge collectors that might approach other conductors or tank walls or ductwork only at the point of discharge. Close spacing over a large area would increase the capacitance of the collectors, and the hazard.

240. Personnel Electrification

2410. The human body is an electrical conductor and in dry atmospheres frequently accumulates a static charge of several thousand volts generated by contact of the shoes with floor coverings, or by participation in various manufacturing operations. Under many conditions, the shoes and clothing of workers are moist enough to drain away static charges as fast as they are generated.

2420. In some occupancies where flammable liquids, gases, or dusts, susceptible to static ignition, are handled, the ability of the body to become charged with static requires careful analysis and study. Such a study might indicate the need for preventing the accumulation of static charge by the use of conductive floors, grounded metal plates, or conductive footwear. Under some circumstances, the wearing of ordinary rubbers, rubber boots, or rubber-soled shoes, should be avoided.

2430. Static shock can result in discomfort and, under some circumstances, injury to workers due to involuntary reaction. If charge accumulation cannot be avoided, and there are no flammable gases or vapor present, consideration should be given to the various methods by which contact with metal parts can be eliminated. Such methods would include, among others, the use of nonmetallic hand rails, insulated door knobs and other nonconducting shields.

2440. Although silk and some synthetic fibers are excellent insulators, and undergarments made from them exhibit static phenomena, there is no conclusive evidence to indicate that wearing such undergarments constitutes a hazard.

2450. Outergarments, on the other hand, can build up considerable static charges when moved away from the body or removed entirely. Under most normal humidity and atmosphere conditions this effect constitutes little hazard. But when humidities are low, as in low temperatures on or in some centrally heated buildings, static potentials increase. Also in some flammable atmospheres enriched with oxygen, the static levels reached from this source may be dangerous. See Code for Use of Flammable Anesthetics, NFPA Standard No. 56, for additional information on synthetic wearing apparel.

250. Semiconductive Materials

2510. Many materials normally considered as insulators may be compounded to render them sufficiently conductive to dissipate dangerous charges of static electricity.

2520. Floor tiles, flooring materials, table tops, hose and tubing, solid tires and casters, footwear, power belting, and other equipment, incorporating such compounding, are available.

260. Aircraft

2610. Aircraft in Flight

2611. Static charges may be developed on airborne objects, such as aircraft, by: (a) the physical contact made by the object with atmospheric water particles (liquid or solid), particularly by dry snow and ice crystals; (b) the physical contact made by the object with other airborne particles, such as dust or smoke, and, (c) by the proximity of object to electrically charged clouds.

2612. Charges generated by physical contact [see (a) and (b) above] are classified as "precipitation" static while the electrification of airborne objects by charged clouds [see (c) above] is called "electrostatic induction."

2613. Electrification of aircraft in flight caused by precipitation static increases about as the cube of the speed of the aircraft (i.e., doubling rate of speed, increases static generation eightfold). Precipitation static may be generated by the microscopic foreign ingredients in the air forced or flowing over aircraft surfaces. The metallic air foils are normally charged negatively by this form of static generation with opposite charges being carried into the slip stream.

2614. The relative position of the charges produced by electrostatic induction from charged clouds on the aircraft's surfaces will change with changes in the orientation of the aircraft with respect to the charged clouds. These changes will be accompanied by compensating electrical current movements and changes of voltage across possible insulating barriers.

2620. Aircraft on the Ground.

2621. An aircraft is similar to any other rubber-tired vehicle, such as an automobile or truck, with regard to its ability to build up a static charge when in movement on the ground or at rest (see Section 550). The difference is principally one of magnitude because of the greater "plate area" of the aircraft. Charges may be generated by movement of air currents over aircraft surfaces where such currents carry particles of dust, snow, or water.

2622. The movement of air over the metallic surface of an aircraft insulated from ground is akin to the generation of precipitation static under flight conditions. The air movement is naturally not so rapid and the charges generated are not usually as great as when airborne. Some ground maintenance operations, however, provide sources of flammable vapors which increase the fire hazard. Generation of static charges in hangars heated by blower systems will usually be found to be greater during cold weather due to the lower humidity and increased circulation of dust particles in the air.

270. Summary

2710. In summarizing, static electricity will be manifest only where highly insulated bodies or surfaces are found. If a body is "charged" with static electricity, there will always be an equal and opposite charge produced. If a hazard is suspected, the situation should be analyzed to determine the location of both charges and to see what conductive paths are available between them.

2720. Tests of the high-resistance paths should be made with an applied potential of 500 volts or more, in order that a minor interruption (paint or grease-film or airgap) will be broken down and a correct reading of the instrument be obtained.

2730. Resistances as high as 10,000 megohms will provide an adequate leakage path in many cases; when charges are generated rapidly, however, a resistance as low as 1 megohm (10^6 ohms) might be required.

2740. Where bonds are applied, they should connect the bodies on which the two opposite charges are expected to be found.

CHAPTER 3. DISSIPATION OF STATIC ELECTRICITY

310. Bonding and Grounding

3110. "Bonding" is the process of connecting two or more conductive objects together by means of a conductor. "Grounding (earthing)" is the process of connecting one or more metallic objects to the ground, and is a specific form of bonding. A metallic object may also be grounded by bonding it to another metallic object that is already connected to the ground. Some objects are inherently bonded or inherently grounded by their contact with the ground. Examples are underground piping or large storage tanks resting on the ground.

3120. Bonding is done to minimize potential differences between metallic objects. Likewise, grounding is done to minimize potential differences between objects and the ground.

3130. Bond wires and ground wires should have adequate capacity to carry the largest currents that may be anticipated for any particular installation. When currents to be handled are small, the minimum size of wire is dictated by mechanical strength rather than current carrying capacity. The currents encountered in the bond connections used in the protection against accumulations of static electricity are in the order of microamperes (one millionth part of an ampere). Because the leakage currents are extremely small, a ground resistance of 1 megohm (one million ohms) would be adequate for static grounding.

3140. Since the bond or ground does not need to have low resistance, nearly any conductor size will be satisfactory from an electrical standpoint. However, to assure adequate mechanical strength, size No. 8 or No. 10 AWG is about the minimum size which should be used. Solid conductors are satisfactory for fixed connections. Flexible conductors should be used for bonds that are to be connected and disconnected frequently.

3141. Conductors may be insulated or uninsulated. Some prefer uninsulated conductors so that defects can be easily spotted by visual inspections. If insulated, the conductor should be checked for continuity at regular intervals, depending on experience.

3142. Permanent connections may be made with pressure-type ground clamps, brazing, welding, or other suitable means (see Figure 7). Temporary connections may be made with battery-type clamps, magnetic or other special clamps which provide metal to metal contact.

3150. There is practically no potential difference between two metallic objects that are connected by a bond wire because the current through a bond wire is generally quite small. However, the situation may be different with an object that is connected to ground, if circumstances are such that the ground wire may be called upon to carry current from power circuits. An object that is connected to ground may, under heavy current flow, develop a high potential difference with respect to ground ($E = I \times R$).

3151. The resistance between a grounded object and the soil is made up of the resistance of the ground wire itself and the resistance of the ground electrode (ground rod) to the soil. Most of the resistance in any ground connection is in the contact of the ground electrode with the soil. The ground resistance is quite variable as it depends upon the area of contact, the nature of the soil, and the amount of moisture.

3152. A typical ground rod may have a ground resistance of 15 ohms. With a current of 30 amperes, for example, the potential of the ground rod and the objects connected to it would reach 450 volts with respect to ground, which is dangerous voltage. It is evident that under such conditions a much lower ground resistance is required to reduce the voltage drop to a safe value. To reduce the ground resistance would require the use of multiple ground rods or a connection to an extensive underground metallic piping system.

3153. Thus, any ground that is adequate for power circuits or lightning protection is more than adequate for protection against static electricity.

320. Humidification

3210. In Chapter 2, materials were loosely described as "conductors," as distinguished from "nonconductors" or "insulators," and it was stated that, since there is no perfect insulator, isolated charges of static electricity always soon leak away. Anything which could be relied upon to impart conductivity to an insulating body would thus become a means of dissipating static charges.

3220. It is a matter of common experience that manifestations of static electricity — e.g., the sparks which an individual may experience on walking across a rug — are more intense in periods of dry weather than they are when a moist atmosphere prevails. From such experience has arisen the erroneous popular belief that static generation is controlled by weather.

3230. Most of the commonly encountered insulating materials, such as fabric, wood, paper, concrete or masonry, contain a certain amount of moisture in equilibrium with the air in the surrounding atmosphere. This moisture content varies, depending on weather, and to a large measure controls the conductivity of the material, and hence its ability to prevent the escape of static electricity. In an analogous manner, under some conditions, water vapor may be absorbed on the surface of some nominally insulating materials, notably glass and porcelain, to render the surface conductive.

3240. The conductivity of the materials under discussion — wood, paper, etc., — is controlled not by the absolute water content of the air but by its relative humidity. This figure, as ordinarily recorded in weather reports and comfort charts, is the ratio of the partial pressure of the moisture in the atmosphere to the partial pressure of water at the prevailing atmospheric temperature. Under conditions of high relative humidity — say 60 to 70 per cent or higher — the materials in question will reach equilibrium conditions containing enough moisture to make the conductivity adequate to prevent static accumulations. The generating mechanism may be present, but the generated charge leaks away so fast that no observable accumulation results.

3241. At the opposite extreme, with relative humidities of 30 per cent or less, these same materials may dry out and become good insulators, and static manifestations become noticeable.

3242. There is no definite boundary line between these two conditions.

3243. It should be emphasized that the conductivity of these materials is a function of relative humidity. At any constant moisture content, the relative humidity of an atmosphere decreases as the temperature is raised. In cold weather, the absolute humidity of the outdoor atmosphere may be low, even though the relative humidity may be high. When this same air is brought indoors and heated, the relative humidity becomes very low. As an example, a saturated atmosphere at an outdoor temperature of 30°F would have a relative humidity of only a little over 20 per cent if heated up to a room temperature of 70°F. This phenomenon is responsible for the common belief that static generation is always more intense during winter weather. The static problem is usually more severe during this period because static charges on a material have less ability to dissipate when relative humidities are low.

3250. Where static electricity has introduced operational problems, such as the adhesion or repulsion of sheets of paper, layers of cloth, fibers, and the like, humidifying the atmosphere has proved to be a solution. It is usually stated that a relative humidity of about 60 to 70 per cent will avoid such difficulties.

3251. Unfortunately, it is not practical to humidify all occupancies in which static might be a hazard. It is necessary to conduct some operations in an atmosphere having a low relative humidity to avoid deleterious effects on the materials handled. High humidity can also cause intolerable comfort conditions in operations where the dry bulb temperature is high. On the other hand, a high humidity may advantageously affect the handling properties of some materials, thus providing an additional advantage.

3252. In some cases localized humidification produced by directing a steam jet onto critical areas, may provide satisfactory results without the need for increasing the humidity in the whole room. (See Article 860.)

3260. It does not follow that humidification is a cure for all static problems. In particular, it must be remembered that the conductivity of the air is not appreciably increased by the presence in it of water in the form of a gas. If static electricity accumulates on some surface which is heated above normal atmospheric temperature — cloth passing over heated rollers for example — alterations in the relative humidity in the surrounding air may do no good whatsoever.

3270. Another situation where the control of atmospheric humidity appears to accomplish little is in controlling the charge of static electricity which under some circumstances appears on the surface of oils. Such a surface does not absorb water vapor in the same way as does paper or wood, so it can remain an insulating surface capable of accumulating static charges even though the atmosphere above it may have a relative humidity up to 100 per cent.

3280. In summary, humidification of the atmosphere to a relative humidity of about 70 per cent may be a cure for static problems where the surfaces on which the static electricity accumulates are those materials which reach equilibrium with the atmosphere such as paper or wood and which are not abnormally heated. For heated surfaces, and for static on the surface of oils and some other liquid and solid insulating materials, high humidity will not provide a means for draining off static charges, and some other solution must be sought.

330. Ionization

3310. General. Under certain circumstances air may become sufficiently conductive to bleed off static charges.

3320. Static Comb

3321. A static charge on a conductive body is free to flow, and on a spherical body in space it will distribute itself uniformly over the surface. If the body is not spherical the self-repulsion of the charge will make it concentrate on the surfaces having the least radius of curvature.

3322. If the body is surrounded by air (or other gas) and the radius of curvature is reduced to almost zero, as with a sharp needle point, the charge concentration on the point can produce ionization of the air, rendering it conductive. As a result, whereas a surface of large diameter can receive and hold a high voltage, the same surface equipped with a sharp needle point can reach only a small voltage before the leakage rate equals the rate of generation.

3323. A "static comb" is a metal bar equipped with a series of needle points. Another variation is a metal wire surrounded with metallic tinsel.

3324. If a grounded static comb is brought close to an insulated charged body (or a charged insulating surface) ionization of the air at the points will provide enough conductivity to make the charge speedily leak away or be "neutralized." This principle is sometimes employed to remove the charge from fabrics (Article 810), power belts (Article 820), and paper (Article 840).

3330. ELECTRICAL NEUTRALIZATION

3331. The electrical neutralizer is a line-powered high voltage device which is an effective means for removing static charges from materials like cotton, wool, silk, or paper in process, manufacturing, or printing. It produces a conducting ionized atmosphere in the vicinity of the charged surfaces. The charges thereby leak away to some adjacent grounded conducting body.

3332. Electrical neutralizers should not be used where flammable vapors, gases, or dust may be present unless approved specifically for such locations.

3340. RADIOACTIVE MATERIAL. Another method for dissipating static electricity involves the ionization of the air by radioactive material. Such installations require no redesign of existing equipment. However, engineering problems are involved, such as health problems, dust accumulations, determination of radiation required, and proper positioning in relation to the stock, machine parts and personnel, which are best worked out in consultation with radiation specialists. See Recommended Safe Practice for Laboratories Handling Radioactive Materials, NFPA No. 801.

3350. OPEN FLAME. Ionization of the air can also be obtained by an open flame (see Paragraph 8445).

CHAPTER 4. CONTROL OF IGNITIBLE MIXTURES

410. Control of Hazard by Inerting, Ventilation or Relocation.

4110. Despite planned efforts to prevent accumulation of static charges, which should be the primary aim of good design, there are many operations involving the handling of nonconductive materials or nonconductive equipment which do not lend themselves to this built-in solution. It may then be desirable, or essential, depending on the hazardous nature of the materials involved, to provide other measures to supplement or supplant static dissipation facilities, such as:

4111. Where the normally ignitible mixture is contained within a small enclosure, such as a processing tank, an inert gas may be used effectively to bring the mixture well below its flammable range. (See Inerting for Fire and Explosion Prevention, NFPA No. 69.) When operations are normally conducted in an atmosphere above the upper flammable limit it may be practicable to apply the inert gas only during the periods when the mixture passes through its flammable range.

4112. Mechanical ventilation may be applied in many instances to dilute an ignitible mixture well below its normal flammable range. Also by directing the air movement, it may be practical to prevent the flammable solvents or dusts from approaching an operation where an otherwise uncontrollable static hazard would exist. To be considered reliable, the mechanical ventilation should be interlocked with the equipment to assure its proper operation.

4113. Where a static accumulating piece of equipment is unnecessarily located in a hazardous area, it is preferable to relocate the equipment to a safe location rather than to rely upon prevention of static accumulation.

CHAPTER 5.
FLAMMABLE AND COMBUSTIBLE LIQUIDS

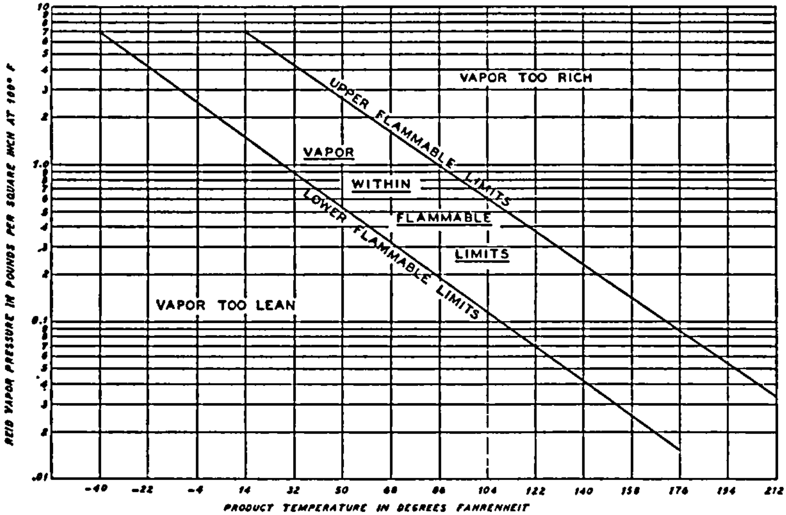
510. General

5110. Flammable liquids may form flammable vapor-air mixtures when being handled or in storage.

5111. If the temperature of the liquid is below its flash point, the mixture above its surface will be below the lower flammable limit or too lean to burn. A liquid handled at or somewhat above its flash point is more likely to have a flammable vapor-air mixture at any free surface. If the temperature of the liquid is far above its flash point, the vapor mixture at the free surface will be above the upper flammable limit or too rich to burn. If the vapor mixture is below or above the flammable limits, it will not ignite, even should a spark occur.

5112. Liquids with a very low flash point, such as gasoline, have, in temperate or tropical climates, a vapor-air mixture at the liquid surface far above the upper flammable limit. Consequently, even if a spark occurs, no ignition results. However, if such liquids are handled at temperatures only slightly above their flash point, ignition becomes a possibility. In temperate climates, kerosene or other high flash point liquids are normally handled at temperatures well below their flash points. Consequently, the vapor-air mixture at the liquid surface is below the lower flammable limit and, here again, no ignition results even though a spark occurs. In the tropics, or when heated, kerosene or other high flash point liquids may reach temperatures at or above their flash points with consequent possibility of ignition.

5113. Thus in general, when a liquid is handled at a temperature such that the vapor-air mixture at the liquid surface is approximately midway between the upper and lower flammable limits, conditions are optimum for ignition. These conditions occur when the liquids are handled at temperatures that are slightly above their flash points; as the handling temperature increases or decreases, the probability of ignition decreases. Graph 1 shows the relationship between temperature, Reid Vapor Pressure, and flammable limits of petroleum products at sea level.



Graph 1. The relationship between temperature, Reid Vapor Pressure, and flammable limits of petroleum products at sea level.

EXAMPLE: With a product such as Hexane (vapor pressure = 5.0), the vapor space of a tank will be within the flammable limits for product temperatures of about −28°F to +26°F, or when handling Heptane (vapor pressure = 1.6) at a product temperature of 55° F, the vapor is within flammable limits and care to prevent static discharge should be taken.

5120. Static is generated when liquids move in contact with other materials. This occurs commonly in operations such as flowing them through pipes, and in mixing, pouring, pumping, filtering or agitating. Under certain conditions, particularly with liquid hydrocarbons, static may accumulate. If the accumulation is sufficient, a static spark may occur. If the spark occurs in the presence of a flammable vapor-air mixture, an ignition may result. Where a static spark and a flammable vapor-air mixture may occur simultaneously, suitable preventive measures are required to avoid ignition.

5121. Filtering with some types of clay and micro-filters substantially increases the ability of liquid flow to generate static charges. Recent tests indicate some filters of this type have the ability to generate charges 10 to 200 times higher than achieved without such filters.

5130. To prevent an ignition it is necessary to control one or more of the following:

a. Flammable vapor.
b. Air (or oxygen).
c. Source of ignition.

5140. Standard control measures are designed to prevent incendiary sparks, or the formation of ignitible vapor-air mixtures. In many cases, air, which might form an ignitible mixture with the vapor, can be eliminated or reduced in amount to render the mixture nonflammable.

5150. From the standpoint of static electricity hazard, flammable liquids may be classified according to the following characteristics:

a. Static-generating (charging tendency) ability.
b. Resistivity.
c. Flash point.

5160. The relative static-generating tendencies of a number of petroleum products have been measured in laboratory tests. In general, aliphatic solvents and lower-boiling hydrocarbons exhibited lower charging tendencies than higher-boiling products. However, the charging tendency of any given product was found to vary widely from one sample to the next. Tables 1 and 2 give reported approximate resistivities of some petroleum products and chemicals. Variations in these tables indicate the difficulties in making these measurements. Reciprocals of the resistivities will provide the values of conductivities.

5170. The production of static electricity by hydrocarbons appears to depend primarily on the presence of trace components which decrease the electrical resistivity. It is not practicable to eliminate completely the production of static by purification of the product. In products of high resistivity, say exceeding about 10^{15} ohm-cm, generation is low because of the absence of such ionizable components.

5171. In products with increased concentration of ionizable trace components (lower resistivity) higher generation may occur, which is only partially offset by the fact that the leakage rate is higher. In products containing still

Table 1

APPROXIMATE RESISTIVITIES OF SOME PETROLEUM PRODUCTS

Product	Resistivity Range Ohm-Centimeter Low	High
Aviation Alkylate	1.5×10^{15}	1.1×10^{16}
Aviation Hydroformate	3.3×10^{12}	8.2×10^{13}
Bunker C	8.1×10^{9}	8.6×10^{8}
Diesel Fuel	1.8×10^{12}	3.1×10^{13}
Fuel Oil No. 5	1.3×10^{10}	1.4×10^{10}
Heating Oil	3.9×10^{8}	5.4×10^{13}
Heavy Catalytic Naphtha	1.8×10^{13}	3.5×10^{13}
Heptane	4.9×10^{12}	4.5×10^{16}
JP-1	9.2×10^{13}	2.7×10^{14}
JP-4	9.9×10^{11}	2.8×10^{14}
Kerosene	9.0×10^{10}	7.3×10^{14}
Octane	1.9×10^{13}	1.5×10^{16}
Solvent Naphtha No. 1	1.7×10^{14}	5.9×10^{15}
Solvent Naphtha No. 7	9.2×10^{13}	7.1×10^{15}
Toluene	1.1×10^{13}	2.7×10^{13}
Tractor Fuel	2.8×10^{13}	4.5×10^{14}
Xylene	2.4×10^{12}	3.0×10^{13}

Source: General Considerations of Static Electricity in Petroleum Products. W. M. Bustin, T. L. Culbertson, C. E. Schleckser, Jr., Esso Research and Engineering Company.

Presented at a symposium on "The Handling of Distillate Fuels" to the Division of Refining during the 37th Annual Meeting of the American Petroleum Institute, November 12, 1957, Chicago, Illinois.

more of these ionizable components, the resistance becomes so low that the charge leaks away as fast as formed, without producing significant charge. Thus, when the electrical resistivity exceeds about 10^{15} ohm-centimeter or is less than 10^{10} ohm-centimeter, net static generation or accumulation is negligible. Between these limits, the net charge generation increases, becoming a maximum when the electrical resistivity is about 10^{13} ohm-centimeter. It might be well to point out that there is no predictable relationship between charging tendency and conductivity. It may be noted that this article is applicable only to bulk charging as distinguished from the charge separation which occurs when a stream of liquid (even a conducting liquid) breaks up into drops as it issues from a nozzle.

Table 2

APPROXIMATE RESISTIVITIES OF SOME PURE LIQUIDS USED IN CHEMICAL INDUSTRIES

Liquid	Resistivity Ohm-Cm
Acetaldehyde	5.9×10^{5}
Acetic Acid	8.9×10^{8}
Acetic Anhydride	2.1×10^{6}
Acetone	1.7×10^{7}
Benzene	1.3×10^{7}
Ethyl Acetate	1.0×10^{9}
Ethyl Alcohol	7.4×10^{8}
Heptane	1.0×10^{13}
Hexane	1.0×10^{18}
Methyl Acetate	2.9×10^{3}
Methyl Alcohol	2.3×10^{6}
Methyl Ethyl Ketone	1.0×10^{7}
n-Butyl Alcohol	1.1×10^{8}
n-Octadecyl Alcohol	2.8×10^{10}
n-Propyl Alcohol	5.0×10^{7}
Sulfuric Acid	1.0×10^{2}
Toluene	1.0×10^{14}
Water	2.5×10^{7}

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

5172. The resistivity of a liquid is a measure of its ability to hold a charge. The higher the resistivity, the greater the ability of the liquid to hold a charge. Liquids having resistivities higher than 10^{10} ohm-centimeter may accumulate a charge. If the resistivity of a liquid is less than 10^{10} ohm-centimeter, any charges that are generated will leak back together without accumulating to a hazardous potential.

5173. Under some conditions water is a good generator of static electricity but usually, due to its low values of resistivity and its wetting properties, the charges leak away as rapidly as produced and electrification is not observed.

5174. Experience indicates that crude oils do not produce static ignitions.

520. Free Charges on Surface of Liquid

5210. If an electrically charged liquid is poured, pumped, or otherwise transferred into a tank or container, the unit charges of similar sign within the liquid will be repelled from each other toward the outer surfaces of the liquid, including not only the surfaces in contact with the container walls but also the top surface adjacent to the air space, if any. It is this latter charge, often called the "surface charge," that is of most concern in many situations.

5220. In most cases the container is of metal, and hence conducting. Two situations can occur, somewhat different with respect to protective measures, depending on whether the container is in contact with the earth or is insulated from it. These two situations are: (1.) an ordinary storage tank resting on earth or concrete or other slightly conducting foundation; and (2.) a tank truck on dry rubber tires.

5230. In the first situation of Section 5220 the metal container is connected to ground through a resistance of less than 1 megohm. The charges that reach the surfaces in contact with the vessel will reunite with charges of opposite sign which have been attracted there. During all of this process the tank and its contents, considered as a unit, are electrically neutral, i.e., the total charge in the liquid and on its surface is exactly equal and opposite to the charge on the tank shell. This charge on the tank shell is "bound" there but gradually disappears as it reunites with the charge migrating through the liquid. The time required for this to occur is called relaxation time. Relaxation time depends primarily on the resistivity of the liquid. It may be a fraction of a second or a few minutes.

5231. During all of this process, the tank shell is at ground potential. Externally, the container is electrically neutral. But internally, there may be differences of potential between the container wall and the fluid, lasting until charges on the fluid have gradually leaked off and reunited with the unlike charges on the tank walls.

5232. If the potential difference between any part of the liquid surface and the metal tank shell should become high enough to cause ionization of the air, electrical breakdown may occur and a spark may jump to the shell. It is such a spark across the liquid surface which is the ignition hazard where flammable vapor-air mixtures are present. No bonding or grounding of the tank or container can remove this internal surface charge.

5240. In the second situation mentioned in Section 5220, the tank shell is highly insulated from the ground. The charge in the oil surface attracts an equal and opposite charge to the inside of the container. This leaves a "free" charge on the outside of the tank, of the same sign as that in the oil, and of the same magnitude. This charge can escape from the tank to the ground in the form of a spark. In filling a tank truck through an open dome, it is this source of sparking which is suspected to have caused some fires; in this case the spark jumps from the edge of the fill opening to the fill pipe which is at ground potential. This hazard can be controlled by grounding the container before filling starts. Usually any resistance path of less than 1 megohm will serve (see Figure 3).

5250. The foregoing discusses the distribution of charges delivered into a container with a flowing stream. Further generation or separation may occur within the container in several ways to produce a surface charge:

a. Flow with splashing or spraying of the incoming stream,

b. Disturbance of water bottom by the incoming stream,

c. Bubbling of air or gas through a liquid, or

d. Jet or propeller blending within the tank.

5260. These charges on the surface of a liquid cannot be prevented by bonding or grounding, but can be rendered harmless by inerting the vapor space, by displacing part of the oxygen with a suitable inert gas, or by increasing the concentration of flammable gas in the vapor space to above the upper flammable limit with a gas, such as natural gas.

530. Storage Tanks

5310. Storage tanks are of two general types: those having a vapor space and those having substantially no vapor space. A cone-roof tank is an example of the former, and a floating-roof tank is an example of the latter.

5320. When cone-roof tanks, or other spaces which *may contain flammable mixtures of vapor and air,* are filled with static-generating liquids, one or more of the following protective measures (Paragraphs a through h) may be used depending upon the characteristics of the liquid handled:

a. Overshot splash filling should be prohibited except for flammable liquids which experience indicates do not cause static ignition, such as crude oils.

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

c. Charge production increases with flow velocity, hence it follows that the occurrence of a static ignition is less likely with low flow velocities. Insofar as practicable, the linear velocity of the liquid in the pipe entering the tank should be kept low until the pipe inlet is well submerged.

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

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

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

g. Gaging or sampling through a roof manway or other roof opening should be avoided for an interval of time after the surface turbulence has subsided or after filling has been completed, especially on large tanks.

h. Care should be exercised to eliminate the chance of any ungrounded floatable objects finding their way into a tank.

5330. When flammable liquids are pumped into a floating-roof tank, the protective measures noted above are applicable until the roof becomes buoyant, after which no special precautions are necessary.

5340. Spark ignitions inside tanks cannot be controlled by external grounding connections (see Article 310 and Section 5230).

5350. An external spark ignition is unlikely unless the tank is deliberately insulated from earth so that the resistance to earth exceeds 10^6 ohms.

540. Closed Piping Systems

5410. Flow through metallic piping generates static but experience has indicated closed piping systems present no static hazard.

5420. Bonding is not needed around flexible metallic piping or metallic swing joints even though lubricated, but a bond should be provided around joints in which the only contacting surfaces are made of nonmetallic insulating material.

5430. In areas where flammable vapor-air mixtures may exist, electrically isolated sections of metallic piping should be bonded to the rest of the system (or grounded) to prevent external sparks which might produce ignition.

550. Rubber-tired Vehicles

5510. Vehicles equipped with pneumatic rubber tires sometimes accumulate a charge of static electricity. This occurs only when the tires are dry and hence good insulators.

5511. Such charging can arise from two separate and unrelated processes — rolling contact of tires on the pavement, or filling fuel and cargo tanks. These are best considered separately, although, since the vehicle is separated from the ground by its tires, the electrical resistance of the tire plays an important part in both cases.

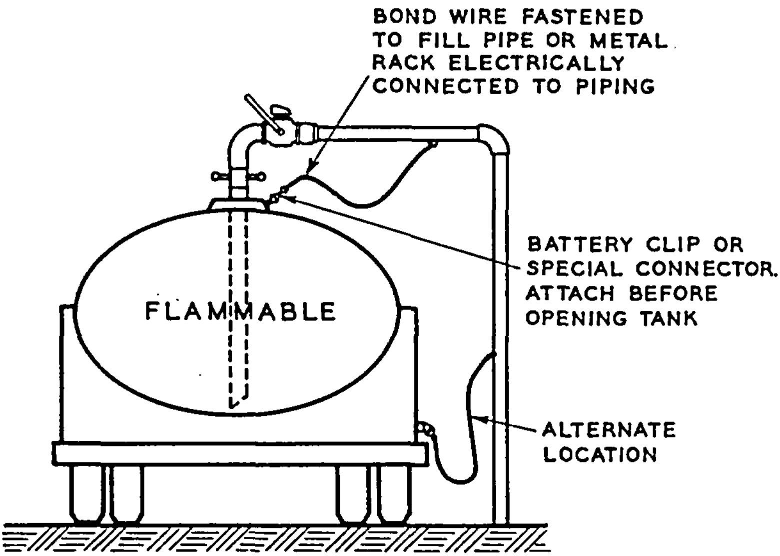


Figure 1

Filling Tank Truck Through Open Dome

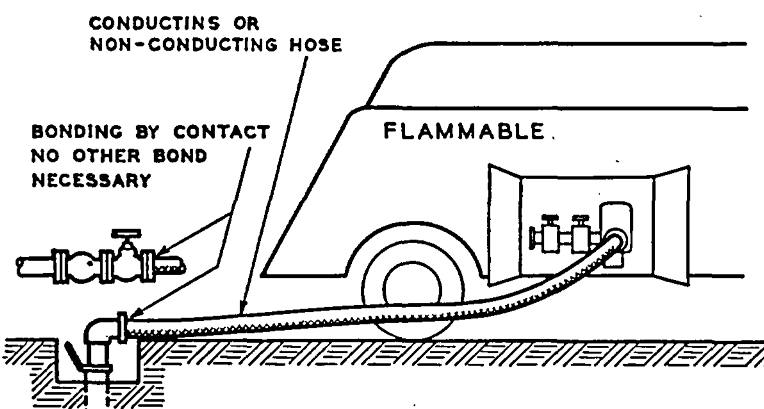


Figure 2

Filling or Emptying Tank Truck Through a Closed Connection

5512. Static from vehicle motion is generated at the point of separation of the tire from the pavement. It becomes significant only at high speed operation when tires and pavement are dry.

5513. Drag chains (drag straps) were originally thought of as a means of bleeding the static charge back to the road as fast as generated. It is now known that a drag chain is ineffective for this purpose when the road is dry and it is of course not needed when the road is wet. Furthermore, drag chains are ineffective as a means of control of static during loading, as discussed below. Their use should not be required.

5520. During filling the fuel tank or cargo tank of automotive equipment with a product having static-generating ability a charge is carried into the tank and will produce a charge on the vehicle. Whether or not this can produce a hazard depends on the amount of charge and other factors, as discussed below:

5521. The total charge carried into a vehicle depends on the generating characteristics and the total quantity of the product delivered. The rate of generation is thus a function of rate of delivery, and for a system of any given dimensions is a function of linear velocity of flow in the pipe lines.

5522. If the vehicle were perfectly insulated from ground, the voltage produced for any given delivery would be determined by the capacitance of the vehicle. Since the tires are not perfect insulators, some leakage occurs which limits the peak voltage which the vehicle may acquire.

5530. When loading tank trucks through open domes at rates of 100 gpm and upward, experience has demonstrated a significant static hazard can be developed. When the vehicle tires are dry, a potential may develop between the vehicle and the grounded piping system, and a spark may jump between the edge of the tank opening and the fill pipe. To avoid this possibility, a bond should be established between the loading piping and the cargo tank (see Figure 1). The bond connection should be made before the dome is opened, and should not be removed until the dome is closed.

5531. The fixed end of the bond wire may be connected to the fill pipe, to any part of a metal loading rack which is electrically connected to the pipe, or to ground. It is not necessary to bond around flexible metallic joints or swivel joints (unless of the insulating type), in the loading pipe. The attachment clip on the bond wire should be a battery clip or some other equivalent attachment so made that it can pull free, thus avoiding inadvertent damage which might result from driving the vehicle away without removing the bond.

5532. Such bonding is not required: (1) when loading vehicles with products not having static-generating abilities, such as asphalt and crude oil; (2) where tank vehicles are used exclusively for transporting Class II or Class III liquids loaded at racks where no Class I liquids are handled; or, (3) where vehicles are loaded or unloaded through closed connections, so that there is no release of vapor at a point where a spark could occur, irrespective of whether the hose or pipe used is conducting or nonconducting. A closed connection is one where contact is made before flow starts and is broken after flow is completed.

5533. Switch loading is a term used to describe a product being loaded into a tank or compartment which previously held a product of different vapor pressure. Switch loading can be a static hazard when low vapor pressure products are put into a cargo tank containing a flammable vapor from previous usage, i.e., furnace oil loaded into a tank which last carried gasoline.

5534. During "switch loading" or when loading products, excluding those enumerated in Paragraph 5532 above, which may give off vapors that are within the flammable range (see Graph 1), the fill pipe should reach as close as possible to the bottom of the tank being loaded, and preferably be in contact with the bottom. If the fill pipe does not reach the tank bottom, the liquid velocity in the fill pipe should be limited to approximately 3 feet per second until the outlet is submerged. If the fill pipe reaches the bottom of the tank or after the outlet of the fill pipe is covered, the velocity may be increased to approximately 15-20 feet per second.

5535. Where bottom loading is used, low velocity or splash deflectors or other devices should be used to prevent upward spraying of the product and to minimize surface turbulence.

5536. All metallic parts of the fill pipe assembly should form a continuous electrically conductive path downstream from the point of bonding. For example, insertion of a nonconductive hose equipped with a metal coupling on the outlet must be avoided unless the coupling is bonded to the fill pipe. This is not required in bottom loading.

5537. Metal or conductive objects, such as gage tapes, sample containers, and thermometers, should not be lowered into, or suspended in, a compartment while the compartment is being filled or immediately after cessation of pumping. A waiting period of approximately one minute will generally permit a substantial relaxation of the electrostatic charge.

5538. Care should be exercised to minimize the possibility of any unbonded object entering into a tank. Prior to loading, tanks should be inspected and any unbonded object removed.

5539. Filters capable of removing micron-sized particles are considered prolific static generators. Therefore, a minimum of 30-second relaxation time normally should be provided downstream of the filter. This means that it should take at least 30 seconds for a particle of liquid to travel from the outlet of the filter element to the outlet of the fill pipe discharge into the tank truck compartment. Relaxation time may be obtained by enlarging or lengthening the pipeline, by installing a retention chamber, or by reducing the flow rate.

5540. No external bond wire or bond wire integral with a hose is needed for the unloading of flammable liquids into underground tanks (see Figure 2).

560. Aircraft.

5610. Fueling and Refueling of Aircraft on the Ground.

5611. When fueling aircraft, the aircraft should first be bonded to the tank truck, drum, fueling cabinet, hydrant or pit, thus providing a low-resistance path to permit reuniting of separated charges; that is, so that charges delivered into the fuel tanks of the aircraft may reunite with charges left on the tank truck or other type of fueler.

5612. When fueling is by over-the-wing delivery, the fuel nozzle should be connected to a metal part of the aircraft which is metallically connected to the fuel tank at a point near the tank fill opening by means of a short bond wire and clip or plug. This connection should be made before the fill cap is removed and the nozzle is placed in the fill opening. It should not be detached until filling has been completed and the fill cap has been replaced.

5613. When fueling is by underwing delivery, the fueling is through a closed system. This closed system provides metal-to-metal contact and thus inherent bonding at the point of connection so that the bond connection mentioned in Section 5620 above is not required.

5614. If nonmetallic conductive hose is used, it shall not be regarded as a substitute for the bonding required in Section 5610 above.

5615. When defueling aircraft, the static-protective measures shall be the same as those taken during fueling operations.

5616. Some regulations require, in addition to the bonding required in this section, that the aircraft and fueling system be connected by wires to ground. However, in many locations grounds are not available and evidence does not indicate that grounding is necessary for protection against static ignition.

5620. Airborne Aircraft.

5621. Bonding of aircraft parts to provide equalization of the potential between various metallic structures of the aircraft is desirable. While such bonding is common, portions of aircraft may be insulated, either because of imperfect bonding or because they are incapable of being electrically bonded (i.e., antenna lead-ins might be a source of static spark inside the aircraft structure when the antenna lead-in is connected to its receiver through a capacitor). Unbonded portions constitute a static fire hazard where flammable vapors are present and an explosion hazard where such flammable vapors exist within confined areas or structures of an aircraft.

5622. High humidity conditions do not aid in the dissipation of static electrical charges on airborne aircraft as is occasioned on objects resting on the ground simply because of the absence of any continuous solid surface between the aircraft and the ground on which a moist film can be deposited. In fact, when humidity reaches the saturation point, an increase in precipitation static results. Small traces of water vapor in a film on an insulator (as might be imparted by condensation) do, however, render the insulator conducting.

5623. Static dissipators can only attempt to approach the theoretical ideal which would be to discharge instantly the electrostatic charges generated on the aircraft so that there would be no difference of potential with the surrounding atmosphere. This is true since ionization cannot start until the impressed potential gradients of the aircraft attain their ionizing threshold intensities. Static dissipators will safely lower dangerous potentials from aircraft if of proper design and installed in adequate number at electrically strategic locations.

5624. It should be stated explicitly that the development of static charges on airborne aircraft offers a fire or explosion hazard only where flammable vapor-air mixtures exist and every effort should be made to eliminate all constructions and procedures which could produce accumulations of such flammable vapor-air mixtures.

570. Tank Cars, Tankers and Barges

5710. Tank Cars

5711. When loading or unloading tank cars through open domes, it is preferable that the downspout be of sufficient length to reach the tank bottom (see Paragraph 5532 for exception).

5712. The resistance of tank car to ground through the rails and the resistance of piping, flexible metallic joints or metallic swivel joints are considered to be adequately low for protection against static electricity.

5713. When loading or unloading tank cars through closed connections, no protective measures need be taken (see paragraph 5532).

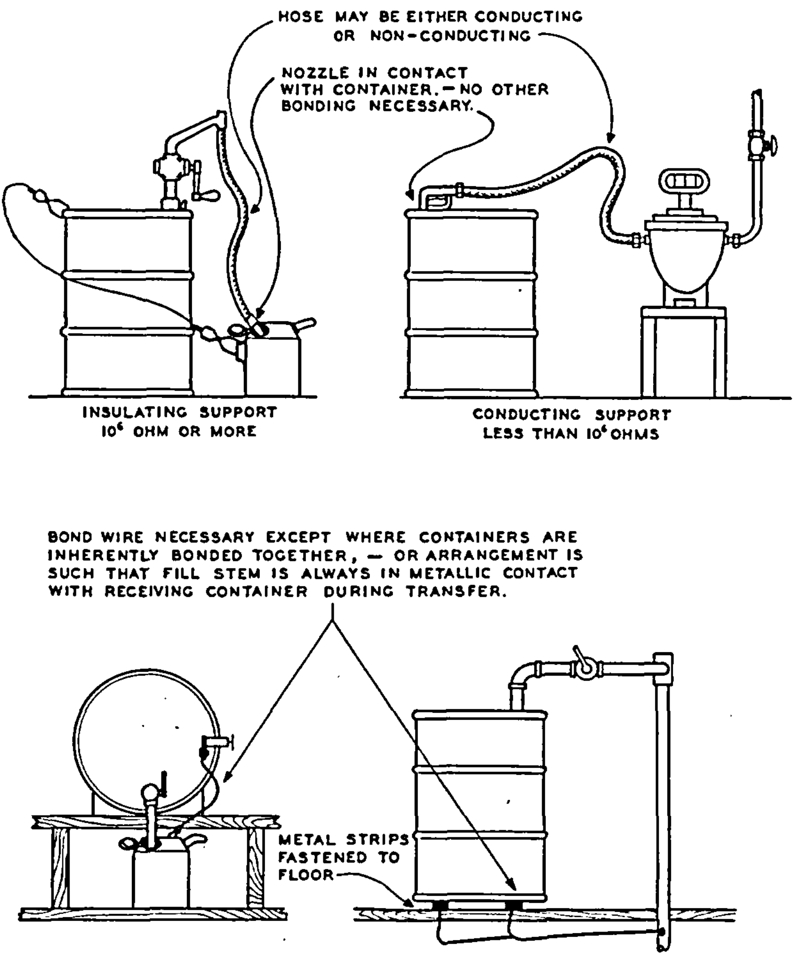


Figure 3

Bonding During Container Filling

5720. Tankers and Barges

5721. The loading and unloading of steel tank ships and barges does not require any special measures to protect against external static sparks. The hull of the vessel is inherently grounded by virtue of its contact with the water. Consequently, the accumulation of static charges on the hull is prevented.

5722. Loading or discharging liquids from vessels is through closed systems. These are, in general, in adequate contact with the earth so that external static sparks are prevented. Even in the unlikely event that an external static spark did occur, it would also be unlikely that this would occur in the presence of a flammable vapor-air mixture (see Articles 530 and 540).

5723. The discussion given in Article 530 regarding pumping of flammable liquids into storage tanks having a vapor space also applies to the flow of such liquids into ships' tanks.

5724. Bonding cables which are often used between ship and shore are sometimes erroneously referred to as "static cables." The purpose of such cables is to prevent arcs caused by stray electrical currents.

580. Container Filling

5810. Filling portable containers is analogous to filling tank vehicles except that the smaller size and lower flow rates permit less rigorous static control measures (see Article 550).

5820. Containers of glass or other nonconducting materials are usually filled without special precaution.

5830. Bonding is not required where a container is filled through a closed system.

5840. In filling metal cans and drums, a fill spout, nozzle, or fill pipe, if conductive, should be kept continuously in contact with the edge of the fill opening. Conductive funnels, strainers, or other devices should likewise be kept in contact with both the fill nozzle and the container to avoid the possibility of a spark at the fill opening. Under these circumstances the additional precaution of providing a bond wire between the container and the fill connection is not warranted, except in special cases where the container being filled is insulated so that the resistance between the container and the fill pipe exceeds 10^6 ohms.

5850. The need for extending a downspout to the bottom of the container has not been demonstrated by experience in filling containers up to and including 55-gallon drums.

5860. When electrical contact cannot be maintained between the fill pipe and the container, a bond wire should be used between them. Figure 3 illustrates various protective measures used in container filling.

590. Blending and Mixing Operations

5910. When mixers, churns, or autoclaves containing flammable liquids are being used, containers and filling lines should be bonded together, if not inherently bonded (see Article 580). However, this will not eliminate the free charge on the surface of the liquid (see Article 520).

5920. Jet mixing and propeller mixing in tanks may generate charges. Care should be taken to avoid agitating a possible layer of water at the bottom of flammable liquid tanks. The jet or propeller stream should be directed so as not to break the surface. Where flammable mixtures may be encountered above the liquid surface, inert gas blanketing may be employed. (See Standard for Inerting for Fire and Explosion Prevention, NFPA No. 69.)

5930. Floating-roof tanks eliminate the vapor space and, therefore, are especially desirable for hazardous blending service.

CHAPTER 6. GASES

610. General

6110. Gases not contaminated with solid or liquid particles have been found to generate little, if any, electrification in their flow.

6120. When the flowing gas is contaminated with metallic oxides or scale particles, etc., or with liquid particles or spray, electrification may result. A stream of such particle-containing gas directed against a conductive body will charge the latter unless it is grounded or bonded to the discharge pipe.

6130. When any gas is in a closed system of piping and equipment, the system need not be electrically conductive or electrically bonded.

620. Air Under Pressure

6210. Compressed air containing particles of condensed water vapor often manifests strong electrification when escaping.

630. Carbon Dioxide

6310. Carbon dioxide, discharged as a liquid from orifices under high pressure (where it immediately changes to a gas and "snow"), can result in static accumulations on the discharge device and the receiving container. This condition is not unlike the effect from contaminated compressed air or from steam flow where the contact effects at the orifice play a part in the static accumulation.

640. Hydrogen-Air, Acetylene-Air Mixtures

6410. Hydrogen-air and acetylene-air mixtures may be ignited by a spark energy of as little as 0.017 millijoule. In the pure state, no static charges are generated by the flow of hydrogen. However, as gaseous hydrogen is commercially handled in industry, such as flowing through pipelines, discharging through valves at filling racks into pressure containers, or flowing out of containers through nozzles, the hydrogen may be found to contain particles of oxide carried off from the inside of pipes or containers. In this contaminated state, hydrogen gas may generate static.

650. LP-Gases

6510. The liquefied petroleum gases (LP-Gases) behave in a manner similar to that discussed in Section 6110 in the gas phase and Section 6120 in the mixed phase.

6520. Bonding is not required where vehicles are loaded or unloaded through closed connections, so that there is no release of vapor at a point where a spark should occur, irrespective of whether the hose or pipe used is conducting or nonconducting. A closed connection is one where contact is made before flow starts and is broken after flow has ended.

CHAPTER 7. DUSTS AND FIBERS

710. General

7110. There are recorded instances where ignition of a dust cloud or layer is attributed to static electrical discharge. Production of static charge is commonly observed during handling and processing of dust in industry. That dust can be ignited by static discharge has been verified experimentally by many investigators.

720. Parameters Affecting Charge Generation

7210. A transfer of an electric charge occurs when two materials in contact are separated. Dust dispersed from a surface may develop a considerable charge. The ultimate charge depends on the inherent properties of the substance, size of particle, amount of surface contact, surface conductivity, gaseous breakdown, external field and leakage resistance in a system. Greater charges develop from smooth than from rough surfaces, probably because of greater initial surface contact. Electrification develops during the first phase of separation. Subsequent impact of airborne particles on obstructions may affect their charge slightly, but if the impact surface becomes coated with the dust, this effect is slight.

7220. Charge generation seldom occurs if both materials are good electrical conductors, but it is likely to occur with a conductor and a nonconductor or two nonconductors. When like materials are separated, as in dispersing quartz dust from a quartz surface, positive and negative charges are developed in the dispersed dust in about equal amounts to give a net zero charge. With materials differing in composition, a charge of one polarity may predominate in the dust. Each of the materials becomes equally charged but with opposite polarity. With a metallic and an insulating material, the former usually assumes positive and the latter a negative polarity.

7230. Electrostatic charge generation in moving dust normally cannot be prevented. High humidity or grounding of the surface from which dust is dispersed will not eliminate the charge generation. The method of dispersion of the dust, the amount of energy expended in dispersal, the degree of turbulence, and the composition of the atmosphere usually do not affect the magnitude or distribution of the charges.

730. Energy Available in Static Discharge

7310. The voltage developed by dispersion of dust from a surface is proportional to the quantity of dust dispersed and the maximum voltage developed depends on the leakage resistance in the system and corona or spark discharge.

7311. The energy (millijoules) in a static discharge is expressed as $\frac{1}{2} CV^2 \times 10^{-9}$, where C is the capacitance (micromicrofarads) and V is the potential difference (volts). The spark energy is dissipated in radiation, in ionization, and in the heating of the gas and dust. The electrostatic voltage thus encountered in industry may range from a few volts to several hundred thousand. Sparks from a fraction of an inch to 8 inches or more in length have been observed.

7312. The capacitance of an object depends upon its physical dimensions, and its proximity to adjacent objects. Generally the capacitance of pieces of machinery is estimated to range from 100 to more than 1,000 micromicrofarads. The capacitance of the human body is approximately 200 micromicrofarads. Thus for average conditions, assuming 10,000 volts, the energy in a static spark discharge from a large insulated machine may be about 50 millijoules and that from a person 10 millijoules.

740. Ignition of Dust by Static Discharge

7410. Dust clouds and layers of many combustible materials (with or without a volatile constituent) have been ignited experimentally by static discharge. In some instances, the charge was generated by movement of dust, in others by a static generator (Wimshurst machine), or by electronic equipment.

7411. With dust clouds, it has been shown that a minimum dust concentration exists below which ignition cannot take place regardless of the energy of the spark. At the minimum dust concentration a relatively high energy is required for ignition. At higher dust concentrations (5 to 10 times the minimum), the energy required for ignition is at a minimum.

7412. The circuit resistance required for optimum igniting power varies with the capacitance, the voltage, and the type of dust; it often ranges from 10,000 to 100,000 ohms. In this connection, it should be noted that metallic dust layers are usually poor electrical conductors unless compressed.

7420. A layer of combustible dust can be ignited by static discharge and will burn with a bright flash, glow, or, for some metallic dusts, with flame. Apparently, there is little correlation in the minimum energy required for ignition of dust layers and clouds. Layers of some metallic dusts such as aluminum, magnesium, titanium, and zirconium require less energy for ignition than carbonaceous materials.

7430. Primary explosives, mercury fulminate, and tetryl, for example, are readily detonated by static spark discharge. Steps necessary to prevent accidents from static electricity in explosive manufacturing operations and storage areas vary considerably with the static sensitiveness of the material being handled.

7440. In all instances in which static electricity was authentically established as the cause of ignition, the spark occurred between an insulated conductor and ground. It has not been verified experimentally that a dust cloud can be ignited by static discharge within itself.

7450. The minimum electrical energies required to ignite some dust clouds and layers are listed in Table 3. Note that many dusts can ignite with less energy than might be expended by a static discharge from machinery or from a human body.

750. Mixing and Blending Operations

7510. Mixing, grinding, screening, or blending operations with solid nonconductive materials can generate static electricity. The degree of static hazard is influenced by the capacity to generate and accumulate a charge of sufficient potential to discharge a static spark capable of igniting any ignitible mixture which may be present in the path of the spark discharge.

Table 3

MINIMUM ELECTRICAL ENERGY (MILLIJOULE) FOR IGNITION OF SOME DUST CLOUDS AND LAYERS

Data from the U.S. Bureau of Mines

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

7520. One of the more common methods employed to drain off static is to bond and ground all metal parts and all moving parts of the equipment. Consequently, metal and other conductive material should be used as far as possible in design of components which are contacted by the solid material being processed, although this may not prevent the static charge on the dispersed dust.

760. Cotton Gins

7610. Research and experience have shown that the amount of energy released by sparks due to static accumulations has not been of sufficient magnitude to ignite loose lint, dust or the cotton.

7620. When the static charge on the cotton is of sufficient magnitude, the cotton will ball up in the gin stands and equipment. This results in a production problem and friction heat in the equipment.

7630. The generation of static on the cotton can be minimized by the introduction of moisture or an antistatic agent.

7640. The bonding and grounding of cotton gin equipment will not prevent or remove the static accumulation from the cotton being processed.

CHAPTER 8. INDUSTRIAL AND COMMERCIAL PROCESSES AND EQUIPMENT

810. Coating, Spreading, and Impregnating

8110. Coating, spreading, and impregnating operations are quite similar to each other in that they each involve the application of solutions such as paints, lacquers, rubber compounds, "dopes," and varnish to fabrics, paper, or other materials. Various methods of applying the coating or impregnating material are employed. These include a doctor blade or knife, flowing roll, squeeze rolls, or calendar rolls and the method used is determined by the viscosity and temperature of the coating or impregnating solution, the speed of the machine, the thickness of the coating desired or the depth of the impregnation.

8120. In each of these operations the material to be processed usually is unwound from a roll at the feed end of the machine, it passes over a series of rollers under a spreader or doctor knife where the coating material is applied, or through an impregnating tank between squeeze rolls and then under a doctor knife, then over a steam table or through a drying oven, and is finally wound up on a reel or laminated on skids. Static charges are often produced in each of these operations.

8130. Where flammable liquids are employed in the process, definite precautions must be taken against possible ignition of flammable vapor-air mixtures. Static eliminators or neutralizers should be installed where the rolls of materials are unwound or where they pass over rolls or under spreader knives or doctor blades. (For bonding of rotating parts, see Article 820.) The frame of the machine should be permanently grounded by a substantial metal conductor that cannot be easily broken or removed.

8140. Where flammable liquids are employed adequate forced ventilation for the area and the equipment is of primary importance and if humidification is not injurious to the process, as it is in some instances, the maintenance of relative humidity of 60 per cent or more will be most helpful in the mitigation of static accumulations. In those areas where high relative humidity can be maintained and adequate forced ventilation is provided, static eliminators may

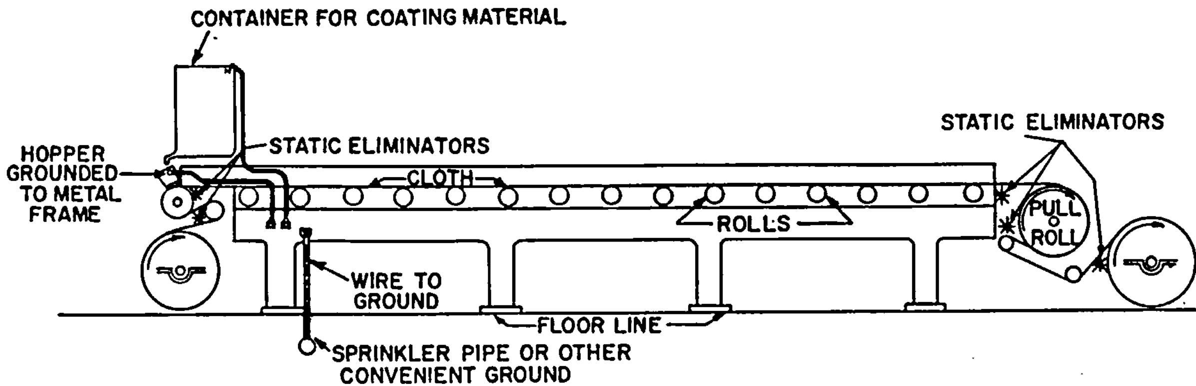


Figure 4

Grounding of Cloth Coating Machine (Metal Frame) Showing Location of Static Eliminators

not be needed. The ventilating fans should also be interlocked with the processing equipment so that they will be in operation before the process can be started (see Article 320).

8150. Local humidification and the installation of steam jets at the feed end of the machine and at other points of static generation have been found in some cases to be a practical means of static control.

8160. Solvent containers such as hoppers should be enclosed and preferably filled through closed piping systems.

820. Transmission Machinery

8210. General

8211. Some types of power transmission machinery frequently exhibit static generation, which may or may not warrant corrective measures depending on circumstances.

8220. Flat Belts

8221. Rubber or leather flat belts running at moderate or high speeds may generate sufficient static electricity to produce sparks several inches long. Such belts are usually dry and good insulators because friction causes them to operate at temperatures higher than the surrounding atmosphere. Generation occurs where the belt leaves the pulley, as a result of the separation, and may occur with either conducting or nonconducting pulleys.

8222. Static generation can be prevented by making the belt conducting by applying some special type of belt dressing. Such coatings must be renewed frequently to be considered practical or reliable.

8223. A grounded metal "comb" with sharp points, placed with the points close to the inside of the belt and a few inches away from the point where it leaves the pulley, will be effective in draining off most of the static (see also Article 330). Such devices may sustain mechanical damage, and are seldom used on power equipment, although