Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents

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Suggested revisions are invited and should be submitted to the Standards Department, API, 1220 L Street, NW, Washington, DC 20005, standards@api.org.This updated publication was prepared under the direction of the API Safety and Fire Protection Subcommittee. The first edition was published in 1956 with subsequent editions in 1967, 1974, 1982, 1991, 1998, and 2008. This eighth edition builds on the technically sound work presented in prior editions. It emphasizes the need to maintain awareness and the continuing need to develop and use sound procedures for controlling hazards and minimizing the possible static ignition risks associated with handling hydrocarbons.

With environmental regulations requiring lower sulfur specification for diesel fuel throughout the world, revisions to the processing to remove sulfur with the need to supplement the new fuels with additives, such as those to improve lubricity, the resultant fuels are much lower in conductivity, often below 2 C.U. This in turn enhances the ability of the fuel to generate and accumulate static charges while flowing through pipes. While there is not a direct correlation between sulfur level and conductivity, current data shows that most low sulfur fuels have low conductivity. The precautionary advice regarding ULSD provided in this eighth edition of API 2003 has been updated to align with recently published guidance in other recommended practices.

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1 Scope

1.1 General

This recommended practice (RP) presents the current state of knowledge and technology in the fields of static electricity, lightning, and stray currents applicable to the prevention of hydrocarbon ignition in the petroleum industry and is based on both scientific research and practical experience. Furthermore, the principles discussed in this RP are applicable to other operations where ignitable liquids and gases are handled. Their use should lead to improved safety practices and evaluations of existing installations and procedures. When the narrow limits of static electricity ignition are properly understood, fire investigators should be encouraged to search more diligently for the true ignition sources in instances where static ignition is unlikely or impossible.

Following this recommended practice is not required where:

a) static discharges may occur, but flammable vapors are verified to be excluded by gas freeing or inerting the atmosphere in the area of discharge;

b) product handling occurs in a closed system, and oxygen in that system is verified to be below the minimum concentration required to support combustion, such as in the handling of liquefied petroleum gas (LPG);

c) the flammable concentration is verified to be above the upper flammable limit (UFL).

This document does not address electrostatic hazards relating to solids handling. (See [4], [5], and [15] in the Bibliography.) Vehicle fueling (truck or passenger car) is also outside the scope of this document.

1.2 Concept of Hazard vs Risk

Hazards are situations or properties of materials with the inherent ability to cause harm. Flammability, toxicity, corrosivity, stored electrical, chemical, or mechanical energy all are hazards associated with various industrial materials or situations. Charge separation and the accumulation of a static charge are inherent properties of low conductivity hydrocarbon fluids.

Risk includes a consequence such as a hot surface or material that can cause thermal skin burns or a corrosive acid can cause chemical skin burns, but these can occur only if there is contact to the skin. An accumulated static charge can be a source of ignition only if exposed to a flammable fuel-air mixture under conditions where a discharge is possible. There is no risk when all the required elements do not exist; charge accumulation, flammable mixture, and spark discharge.

Determining the level of risk involves estimating the probability and severity of exposure of an event that could lead to harm. While the preceding examples relate hazards to the risk to people, the same principles are valid for evaluating risks to property and the environment. For instance, hydrocarbon vapors in a flammable mixture with air can ignite if exposed to a source of ignition (such as a static discharge) resulting in a fire which could injure people or damage property.

1.3 Units of Measurement

Values for measurements used in this document are generally provided in both U.S. customary and SI (metric) units. To avoid implying a level of precision greater than intended, the second cited value may be rounded to a more appropriate number. Where specific code or test criteria are involved, an exact mathematical conversion is used. Some conversions are included in Annex D.

2 Normative References

No single publication covers all the material needed to understand electrostatic ignition of hydrocarbons and the appropriate protection against such ignition. The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

API/EI Standard 1529 [1], *Aviation fueling hose* and hose assemblies

API Recommended Practice 2027, *Ignition Hazards and Safe Work Practices for Abrasive Blasting of Atmospheric Storage Tanks in Hydrocarbon Service*

API Recommended Practice 2219, *Safe Operation of Vacuum Trucks in Petroleum Service*

API Standard 650, *Welded Steel Tanks for Oil Storage*—Annex H

API/ANSI Standard 2015, *Requirements for Safe Entry and Cleaning of Petroleum Storage Tanks*

API/ANSI Recommended Practice 2016, *Guidelines and Procedures For Entering and Cleaning Petroleum Storage Tanks*

API Recommended Practice 545, *Recommended Practice for Lightning Protection of Aboveground Storage Tanks for Flammable or Combustible Liquids*

AIChE/CCPS [2], *Electrostatic Ignitions of Fires and Explosions*, Thomas H. Pratt ISBN 0-8169-9948-1 (with errata)

AIChE/CCPS, *Avoiding Static Ignition Hazards in Chemical Operations*, L. G. Britton, ISBN 0-8169-0800-1

ASTM D323 [3], *Standard Test Method for Vapor Pressure of Petroleum Products* (Reid Method)

ASTM D2624, *Standard Test Methods for Electrical Conductivity of Aviation and Distillate Fuels*

ASTM D4308, *Standard Test Method for Electrical Conductivity of Liquid Hydrocarbons by Precision Meter*

ISO 1813 [4], *Belt Drives—V-ribbed belts, Joined V-belts and V-belts including wide section belts and hexagonal belts—Electrical conductivity of antistatic belts: Characteristics and methods of test*

ISO 9563, *Belt Drives—Electrical conductivity of antistatic endless synchronous belts—Characteristics and test method*

NFPA [5], *Fire Protection Guide to Hazardous Materials*, 14th Edition

NFPA 30, *Flammable and Combustible Liquids Code*, 2015 Edition

NFPA 30A, *Code for Motor Fuel Dispensing Facilities and Repair Garages*, 2015 Edition

NFPA 69, *Standard on Explosion Prevention Systems, 2014 Edition*

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1 Energy Institute, formerly the Institute of Petroleum, 61 New Cavendish Street, London W1G 7AR, UK, www.energyinst.org.
2 American Institute of Chemical Engineers, Center for Chemical Process Safety, 3 Park Avenue, 19th Floor, New York, New York 10016, www.aiche.org/ccps.
3 ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, www.astm.org.
4 International Organization for Standardization, 1, ch. de la Voie-Creuse, Case postale 56, CH-1211, Geneva 20, Switzerland, www.iso.org.
5 National Fire Protection Association, 1 Batterymarch Park, Quincy, Massachusetts 02169-7471, www.nfpa.org.

NFPA 70, *National Electrical Code®*, 2014 Edition

NFPA 77, *Recommended Practice on Static Electricity*, 2014 Edition

NFPA 407, *Standard for Aircraft Fuel Servicing*, 2012 Edition

NFPA 780, *Standard for the Installation of Lightning Protection Systems*, 2014 Edition

OCIMF [6], *International Safety Guide for Oil Tankers and Terminals* (*ISGOTT)*, 5th Edition 2006

3 Terms, Definitions, Acronyms, and Abbreviations

3.1 Terms and Definitions

For the purposes of this document, the following definitions apply.

3.1.1
arc
An electrical discharge that occurs at the instant two points, through which a large current is flowing, are separated. Technically, electrostatic discharges are always sparks, not arcs.

3.1.2
bonding
The practice of providing electrical connections between isolated conductive parts of a system to preclude voltage differences between the parts (see Figure A.5). The low current associated with static charges can be satisfactorily bled off using small wires over long distances. In field use, a strong wire resistant to physical damage may be needed, in which case a bond wire may be sized for physical or mechanical strength. These larger wires typically have low resistance. The process of connecting two or more conductive objects together by means of a conductor so that they are at the same electrical potential does not necessarily mean they are at the same potential as the earth.

NOTE A bond resistance as high as 1 megohm (10^6 ohms) can be adequate for static dissipation. However, for stray current protection, lightning protection, and other electrical systems, the bonding resistance needs to be significantly lower, no more than a few ohms.

3.1.3
closed connection
A connection in which contact is made before flow starts and is broken after flow is completed (e.g. bottom loading of tank trucks).

3.1.4
combustible liquid
A liquid with a flash point at or above 100 °F (38 °C) as defined by NFPA 30.

3.1.5
conductivity
σ
The capability of a substance to transmit electrostatic charges, normally expressed in picoSiemens per meter (pS/m) or conductivity units. For petroleum products, the following conductivities are defined for the liquid temperature during transfer operations. Conductivity measurements at laboratory temperature shall be adjusted to represent transfer temperature using rationale such as explained in Annex B.6.

High Conductivity—measured conductivity above 50 conductivity units (C.U.)
Low Conductivity—measured conductivity less than 50 C.U. but no less than 2 C.U.
Ultra-low Conductivity—measured conductivity 2 C.U.

[6] Oil Companies International Marine Forum, 27 Queen Anne's Gate, London, SW1H9BU, England, www.ocimf.com.

3.1.6
conductivity unit
C.U.
A unit of electrical conductivity equal to 1 pS/m where 1 pS/m = 1×10^{-12} siemens per meter = 1×10^{-12} ohm^{-1} m^{-1}. (The pS/m unit represents the same conductivity value as the now obsolete picomho/m.)

3.1.7
flammable liquid
A liquid as defined by NFPA 30 having a flash point below 100 °F (38 °C) and having a Reid vapor pressure (RVP) not exceeding 40 psia (276 kPa).

3.1.8
grounding
NFPA 77 defines grounding as 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"). For hydrocarbon transfers this is accomplished by providing electrical continuity between a fuel handling system and ground or earth to ensure that the fuel handling system is at zero potential (see Figure A.6). A resistance as high as 1 megohm is adequate for static dissipation. For other purposes, such as electrical systems, lightning protection, etc., very much lower resistances are needed.

3.1.9
hazard
A situation or inherent chemical or physical property with the potential to do harm (flammability; oxygen deficiency; toxicity; corrosivity; stored electrical, chemical, or mechanical energy).

3.1.10
high vapor pressure products
Liquids with a Reid vapor pressure 100 °F (38 °C) above 4.5 psia (31 kPa). These products include aviation and motor gasoline and high vapor pressure naphtha.

3.1.11
intermediate vapor pressure products
Flammable liquids with a Reid vapor pressure 100 °F (38 °C) below 4.5 psia (31 kPa) and a closed-cup flash point of less than 100 °F (38 °C). These can form flammable vapors at ambient operating temperatures. Examples of these products are commercial aviation fuel (Jet B), military aviation turbine fuel (JP-4, TF-4), and solvents such as xylene, benzene, and toluene.

3.1.12
low vapor pressure products
Liquids with closed cup flash points above 100 °F (38 °C). Examples of these products include heating oil, kerosene, diesel fuel, commercial aviation turbine fuel (Jet A), and "safety solvents."

3.1.13
Reid vapor pressure
RVP
The vapor pressure of a petroleum product in a closed vessel at 100 °F (38 °C) (ASTM D323).

3.1.14
relaxation time constant
The time for a charge to dissipate to e^{-1} (approximately 37 %) of the original value. In general, for hydrocarbon liquids, relaxation time constant is approximated by the relationship:

$$\tau = 18/\sigma$$

where

τ is relaxation time in seconds;

σ is electrical conductivity of the liquid in pS/m.

As an example, a liquid with a conductivity of 6 pS/m would have a relaxation time constant of 3 seconds. Pratt notes that a charge can be considered "practically dissipated" after three time constants and "completely dissipated" after five time constants. For program purposes the relaxation time constant is calculated [5].

3.1.15
residence time
The length of time that a product remains in a grounded conductive delivery system from the point at which a charge is generated before it reaches the point of delivery, e.g. from the outlet of a pump, an inline filter or a microfilter to the inlet of a tank truck, a tank or marine vessel. System configuration and operating parameters determine residence time.

3.1.16
risk
The probability and consequences of exposure to a hazard, hazardous environment or situation which could result in harm.

3.1.17
risk assessment
The identification and analysis, either qualitative or quantitative, of the likelihood and outcome of specific hazard exposure events or scenarios with judgments of probability and consequences.

3.1.18
risk-based analysis
A review of potential needs based on a risk assessment.

3.1.19
spark
A spark results from the sudden breakdown of the insulating strength of a dielectric (such as air) that separates two electrodes of different potentials. NFPA 77 defines spark as: "A short-duration electric discharge due to a sudden breakdown of air or some other insulating material separating two conductors at different electric potentials, accompanied by a momentary flash of light; also known as electric spark, spark discharge, or sparkover."

3.1.20
splash filling
The practice of allowing fuel to free fall or to impinge at high velocity on a tank wall, tank bottom, or liquid surface while loading creating droplets passing through the vapor space inside the tank or vessel.

3.1.21
spray deflector
A plate above the vessel inlet opening that prevents upward spraying of product and minimizes the generation of a charged mist.

3.1.22
static accumulator
Unless otherwise stated in the body of this recommended practice, a static accumulator is a liquid with a conductivity less than 50 pS/m.

3.1.23
static dissipater additives
SDA
Materials added in low quantities to improve the ability of low viscosity fluids to dissipate (relax) a static charge through increased conductivity. These are sometimes called "conductivity improvers." In the past these were referred

to as “anti-static” additives, but since they do not reduce the rate of static charge generation they are technically not “anti-static.”

3.1.24
split loading
Using separate compartments of the same vehicle to hold different products.

3.1.25
spread loading
Defined by *ISGOTT* as the practice of commencing loading via a single shore line to several of the ship’s cargo tanks simultaneously where it is necessary to mitigate a terminal’s lack of flow control. The aim of this practice is to achieve a loading rate that will give a maximum velocity at each of the tank inlets not exceeding 3 ft/s (1 m/s).

3.1.26
switch loading
The practice of loading a low conductivity, low vapor pressure product into a fixed or portable tank or truck which previously contained a high or intermediate vapor pressure product (such as gasoline or solvent), resulting in a flammable atmosphere while loading the low vapor pressure product.

3.1.27
verify
Confirming the accuracy of a value or condition by testing, analysis, measurement or observation to validate the information being used.

3.1.28
waiting period
The elapsed time after the completion of product dispensing into storage or transportation containers (i.e. storage tanks, tank trucks, and tank cars) before sampling or gauging activities.

3.2 Acronyms and Abbreviations

C.U.	conductivity unit
IGS	inert gas systems
LPG	liquefied petroleum gas
pS/m	picoSiemens per meter
RVP	Reid vapor pressure
SDA	static dissipater additives
ULSD	ultra-low sulfur diesel

4 Static Electricity Hazards

4.1 General

4.1.1 Fundamental Considerations

The generation of electric charges, their accumulation on material, and the process of dissipating these accumulated charges cause static electricity hazards. See Annex A for a more detailed discussion of the fundamentals of static electricity.

Sparks from static electricity are a source of ignition. For an electrostatic charge to be a source of ignition, four conditions must be present:

1) a means of generating an electrostatic charge (see 4.1.2),

2) a means of accumulating an electrostatic charge capable of producing an incendiary spark (see 4.1.3),

3) a spark gap (see 4.1.4), and

4) an ignitable vapor-air mixture in the spark gap (see 4.1.5).

Ignition hazards from static sparks can be eliminated by controlling the generation or accumulation of static charges or by eliminating a flammable mixture where static electricity may be discharged. The risk of ignition can also be reduced if spark promoters are avoided in areas of potentially high electric field (see 4.1.4.5).

4.1.2 Charge Generation

This publication considers practical procedures for protecting specific petroleum operations from the hazards of static electricity. The very nature of these operations involves the transport of various types of petroleum products. This movement of product generates a static charge within the product.

Static electricity is commonly generated by the movement of materials because it involves the separation or pulling apart of surfaces that are in intimate contact with each other. This is also referred to as Triboelectic (frictional) charging. When two bodies of dissimilar materials are in close physical contact with one another, there is often a transfer of free electrons. If one or both of the materials are poor conductors, uneven charges cannot quickly recombine. A sudden separation will leave the excess electrons on one of the bodies and a deficiency of electrons on the other. If the two bodies are then insulated from their surroundings, they will tend to accumulate equal and opposite charges. The body having the excess electrons will be negatively charged and the one with an electron deficiency will be positively charged. The electrical potential difference between the charged bodies can easily reach several thousand volts.

Some common examples of separation or Triboelectic generation of static electricity are provided below.

a) Discharge of liquid or gas from a hose, nozzle, faucet, or pouring spout.

b) The movement of liquids, gases, or solid particles relative to other materials, such as occurs commonly in operations involving flow through pipes, mixing, pouring, pumping, filtering, agitating, or other types of fluids handling.

c) Turbulent contact of dissimilar fluids, such as water or gas flowing through a liquid hydrocarbon.

d) Air, gas, or vapors containing solid particles (e.g. dust, rust, etc.) or droplets being discharged from a pipe or jet. Discharge of carbon dioxide extinguishers, sand blasting, steam lances, and pneumatic transportation of solids are examples.

e) Separation of immiscible liquids or suspended solids in a liquid. e.g. settling of a dispersed water phase in a storage tank.

f) Nonconductive drive belts and conveyor belts moving across or separating from rollers or pulleys.

g) Induction Charging as defined in NFPA 77 is the process where a grounded conductive object can become charged when it is brought near a highly charged surface and the connection to ground is then broken. Charge polarization can be induced on a grounded object that is in the vicinity of a charged surface due to the electric field that exists between the object and the surface. If the ground connection is removed from the object during this period, the induced charge remains on the object. For example, an inducted charge occurs where a person walks from a conductive floor covering onto one that is insulated in the presence of an electric field.

4.1.3 Charge Accumulation and Relaxation

Electrostatic charges continually leak away from a charged body. Dissipation of the charge starts as soon as a charge is generated and can continue after charge generation has stopped. Electrostatic charges accumulate when they are generated at a higher rate than they dissipate. The ability of a charge to dissipate from a liquid is a function of the following:

a) the conductivity of the product being handled;

b) the conductivity of the container;

c) the ability of the container to bleed a charge to ground.

In a grounded conductive container, the ability of a liquid to dissipate a charge is governed by the liquid's conductivity. The higher the conductivity, the faster the charge dissipates. Generally, liquids with conductivity greater than 50 pS/m (50 C.U.) do not accumulate static charges provided the material is handled in a grounded conductive container. Above 50 pS/m, charges tend to dissipate as fast as they are generated. Table A.1 lists conductivities of some typical liquids handled in petroleum operation.

For liquids with conductivity greater than 2 pS/m, the charge relaxation follows an exponential decay proportional to the relaxation time constant. Liquids with lower conductivity follow a hyperbolic decay. This may create dissipation times shorter than predicted by exponential decay. This is discussed in more detail in Annex A.5.

Charges can also accumulate regardless of the conductivity of the fluid if the container being filled is made of low-conductivity (nonconductive) material (e.g. a plastic bucket), or if the container is conductive but is inadequately grounded. A metallic (conductive) fuel container resting on a plastic bed liner of a pick-up truck is an example. See 4.2.2 for guidance on bonding and grounding.

4.1.4 Static Discharge Mechanisms

4.1.4.1 General

As electrostatic charge accumulates, the electric fields and voltages increase. When the electric field exceeds the insulating properties of the atmosphere, a static discharge can occur. Two types of static discharges are of primary concern in the petroleum industry: spark and brush discharges.

4.1.4.2 Spark Discharge

Spark discharges occur between conductive objects that are at different voltages. Usually, one of the objects is not adequately grounded. An example would be a metal can floating on a static accumulator and the side of a tank-truck compartment. Avoiding ungrounded and unbonded conductive objects through sound design, maintenance, and operating practices can prevent this type of spark.

4.1.4.3 Brush Discharge

Brush discharges can occur between a grounded conductive object and a charged low conductivity material. An example would be a spark between the bottom of a filling arm and the surface of the product during splash loading. Brush discharges can be eliminated by avoiding the charge build-up on the product through adequate residence times, flow rate restrictions, etc., and by designing and operating equipment to avoid conductive objects protruding into the container.

4.1.4.4 Incendive Discharge

A discharge that has enough energy to cause ignition is considered incendive. Both spark discharges and brush discharges can ignite common hydrocarbon/air mixtures.

4.1.4.5 Spark Promoters

A spark promoter is a grounded or ungrounded conductive object that provides the necessary spark gap for a spark to occur. Spark promoters greatly increase the probability of an incendive discharge. An important class of spark promoters is conductive objects near the surface of the charged liquid. The following are some examples of spark promoters:

a) loose floating conductive objects or debris inside the container;

b) conductive downspout which does not reach the bottom of the tank;

c) gauge rods or side wall probes which are not connected to the bottom;

d) gauge tapes, sample containers or thermometers which are lowered into the tank vapor space;

e) ungrounded couplings on hoses in the tank.

Two types of spark promoters are shown in Figure 1 and Figure 2. Care in design, maintenance, and operation should be exercised to avoid spark promoters.

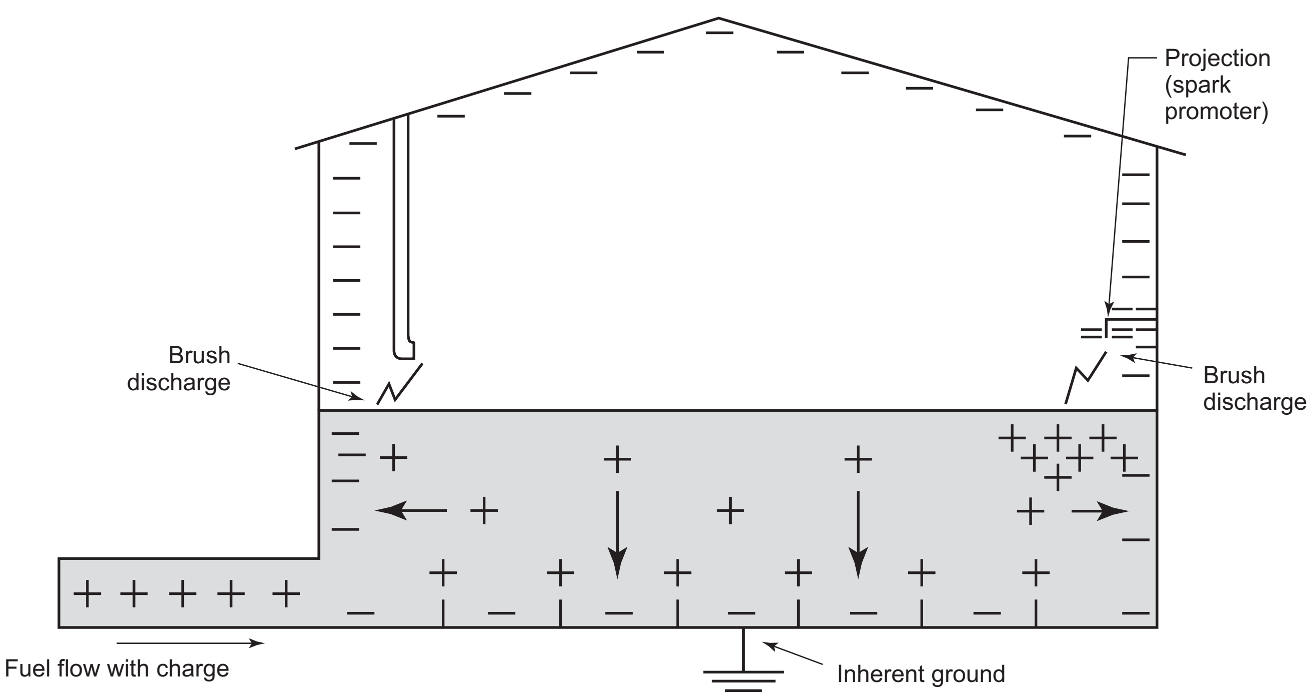


Figure 1—Fixed Spark Promoter

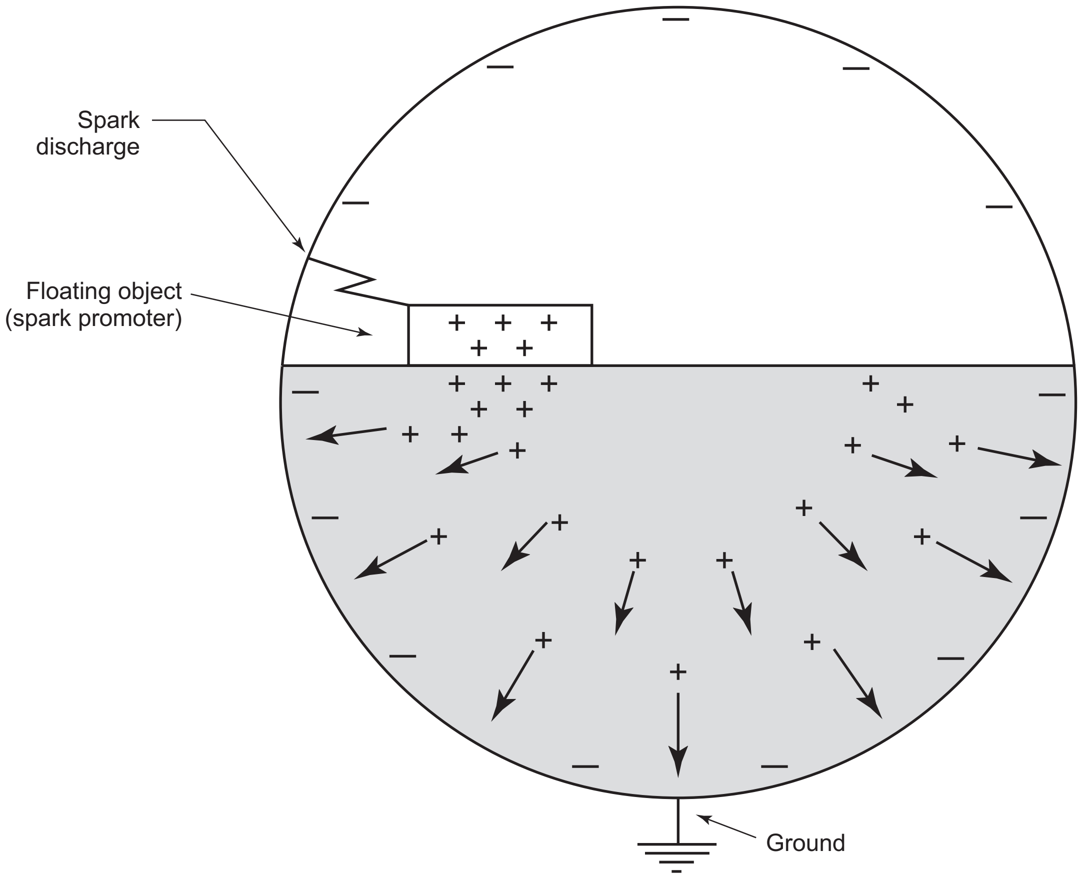


Figure 2—Floating Spark Promoter

4.1.5 Flammable Vapor-air Mixtures

4.1.5.1 General

The probability of a vapor-air mixture being flammable depends on the product's vapor pressure, flash point, temperature, and pressure at which it is handled. These properties are used to classify refined products. For the purpose of electrostatics, these classifications are low vapor pressure products, intermediate vapor pressure products, and high vapor pressure products (see Section 3 for definitions).

Intermediate vapor pressure products create a flammable mixture in the vapor space of storage containers at ambient temperatures.

Low vapor pressure products are generally handled at temperatures well below their flash points. Under these conditions they do not develop flammable vapors. However, a condition for ignition may exist for these products under the following situations:

a) Handled at temperatures near [within 15 °F or 20 °F (8.5 °C to 11 °C)] or above their flash points. Some companies choose the 20 °F (11 °C) limit as more protective because product temperature and flash point measurements can be uncertain.

b) Contaminated with intermediate or high vapor pressure products, e.g. producing a flammable gas-air mixture in the vapor space of a fixed-roof storage tank if dissolved hydrogen or other light hydrocarbon from a treating process is carried over and released into the tank.

c) c)Transferred into containers where flammable vapors are present from a previous use, e.g. the condition may occur during switch loading, as described in 4.1.5.2.

d) Handled in a manner which generates fuel mists, e.g., under certain handling conditions, low vapor pressure products can form a flammable mist at temperatures below the liquid's flash point. Ignitions have been attributed to electrostatically charged mists.

When high vapor pressure products are loaded into a gas-free compartment or tank, the vapor space will pass through the flammable range. However, vapor just above the surface may become too rich very quickly while other areas in the compartment may not rapidly become too rich rapidly. In these areas the possibility of incendiary sparking in these areas must be considered. A flammable mixture may still form and exist around an open vent and may be present during and after the transition to an over-rich mixture; thus, any sparks in such regions can ignite a flammable mixture. When high vapor pressure products are handled at low temperatures, a flammable mixture may be created in the normally too-rich vapor space because fewer vapors are released at lower temperatures. Under such circumstances, these products should be handled as intermediate vapor pressure products.

Figure 3, which shows the approximate correlation of Reid vapor pressure and product temperature to the flammable range (at equilibrium conditions), may be useful in estimating the temperature range within which a flammable vapor-air mixture is likely to exist.

4.1.5.2 Switch Loading and Special Situations

Experience shows that many static related incidents have occurred during switch loading. Switch loading is the most frequently cited cause of static incidents when handling bulk hydrocarbons. Loading heating oil, diesel fuel or lubricating base oil with low electrical conductivity into a tank that previously contained gasoline is an example of switch loading. Even when the compartment appears free from standing liquid from the previous load the tank or compartment can contain a flammable mixture. Residual vapors from the previous high or intermediate vapor pressure cargo in an "empty" tank mixed with air can be in the flammable range. Static electricity can accumulate (4.1.3) when loading a low conductivity, low vapor pressure product. For a given set of conditions there can be a static discharge and ignition (4.1.4).

Other situations can also result in flammable atmospheres where they would not be typically expected. The following examples are not meant to be all-inclusive.

a) Extremes in product temperature (e.g. a high vapor pressure product in cold temperatures or a low vapor pressure product in hot temperatures).

b) Conditions that produce mists or foams.

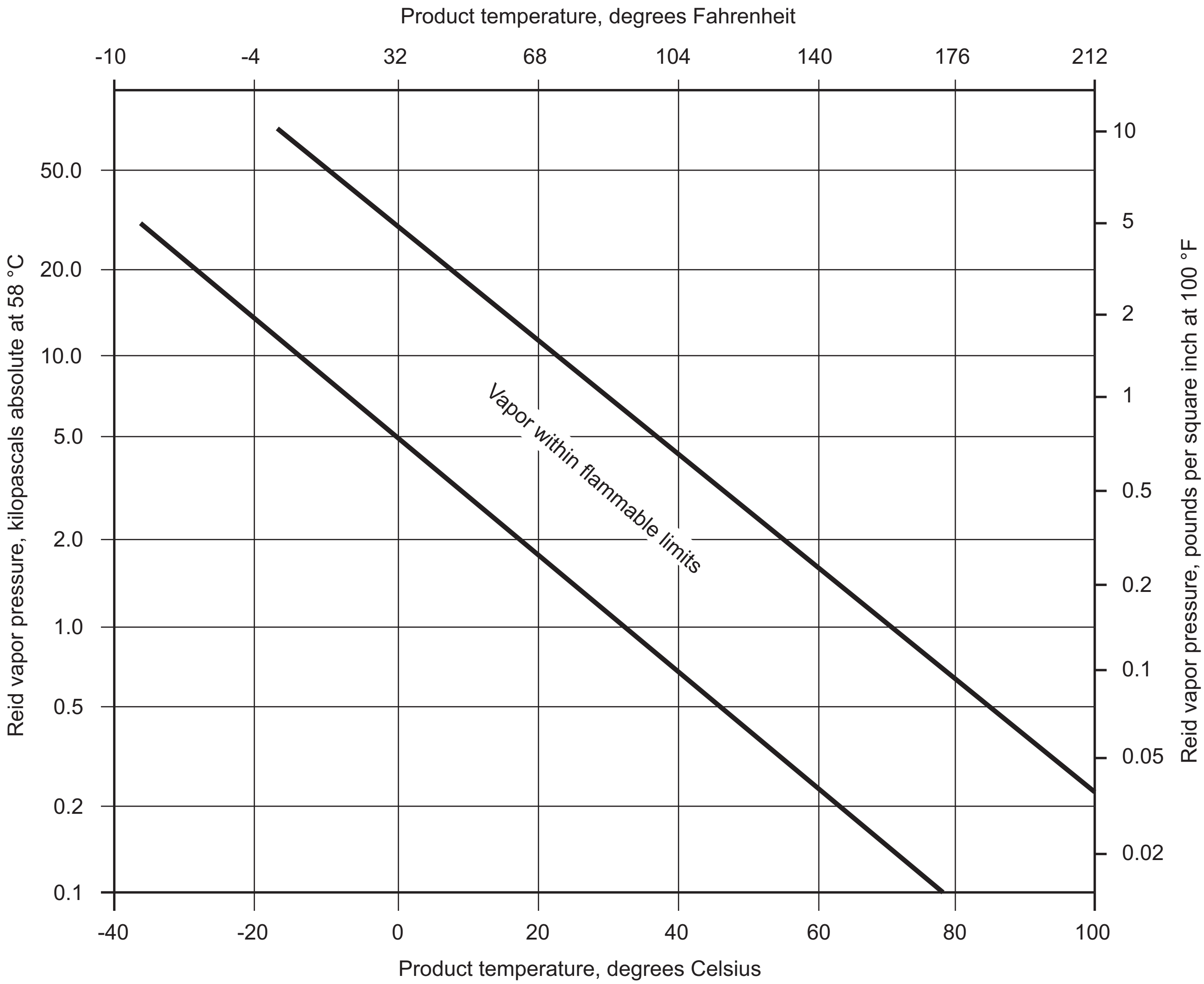
c) Contamination with other hydrocarbon products, either vapor or liquid. For example, as a result of a leak in the bulkhead between tank truck compartments or cross-contamination in the distribution system.

d) Contamination from inadequate flushing of product lines and other equipment before another product is introduced (such as may occur with switch loading).

e) Loading manifolds with bypass valves that allow inadvertent mixing.

f) Cross connection of the vapor spaces of different compartments that contain different vapor pressure stocks (e.g. via a vapor recovery system).

g) Partial loads of low vapor pressure material that may not completely absorb or displace vapors from a previously-carried high vapor pressure cargo. (e.g. A situation where gasoline was originally carried in the compartment; followed by flushing with a partial load of diesel that leaves the vapor space in the flammable range; followed by



NOTE Caution should be exercised when dealing with conditions near the boundaries of this estimate since it is not necessarily conservative in all cases.

Figure 3—Approximate Relationship Between Temperature, Reid Vapor Pressure, and the Flammability Limits of Petroleum Products at Sea Level

loading diesel. This second diesel loading operation would not normally be recognized as switch loading, but has the same effect.)

h) Vacuum truck operations where operating pressures are below atmospheric increasing vaporization in the tank.

i) Hybrid mixtures are mixtures of suspended combustible dust and flammable gas or vapor where neither is present in sufficient quantity to support combustion but where the mixture can support combustion.

4.1.6 Preventive Measures

4.1.6.1 A variety of preventive measures can be considered to reduce the risk of static discharge. Not all of these measures are applicable in every situation. Examples include the following.

To prevent charge generation:

a) avoid splashing and misting operations (e.g. in filling operations);

b) limit initial fill rates and maximum flow rates (e.g. in filling operations);

c) avoid pumping or flowing hydrocarbons with dispersed water or solids;

d) control hydrocarbon flow velocities in all applicable piping segments;

e) avoid use of free-flowing steam to “inert” a potentially flammable vapor space as wet steam has been described as a significant generator of electrostatic charge, carbon dioxide has similar properties when “snow” is formed at the nozzle.

4.1.6.2 To prevent charge accumulation:

a) use sufficient residence time downstream of pumps and filters;

b) ground conductive fluids while filling insulated containers;

c) use bonding and grounding to prevent buildup of potential differences between conductive parts (e.g. in flowing, pouring, steaming, and blasting operations);

d) add SDA to low conductivity fuels to raise conductivity, preventing charge accumulation in grounded equipment (see Annex A.8.5).

4.1.6.3 To avoid incendive spark discharge:

a) remove or bond spark promoters in tanks and vessels (see 4.2.3);

b) use sufficient waiting period before sampling or gauging.

To avoid flammable atmospheres:

a) displace air with nitrogen or other inert gas supplied in a manner not to generate a static charge;

b) fill vapor space with over-rich vapor;

c) avoid loading low vapor pressure products at high temperature;

d) avoid loading high vapor pressure products at low temperature;

e) avoid switch loading;

f) operate the pipe or container liquid full (no vapor space);

g) operate at least 20 °F (11 °C) less than the flash point.

4.1.7 Evaluating In-use Conductivity

In order to properly evaluate the electrostatic charging hazard during transfer operations, the following factors must be considered to verify the conductivity of the product being loaded:

— to be relevant, the conductivity used for hazard evaluation must represent conductivity at transfer temperature since conductivity is significantly reduced as temperature becomes lower;

— conductivity considerations should recognize and evaluate the potential impact of conductivity measurement error (instrument reproducibility and accuracy (see Annex B and relevant ASTM standards);

— where conductivity evaluation depends on measurement using product samples there is potential for non-representative samples, including possible stratification in the tank or vessel being sampled;

— water and other contaminants or component variations can substantially increase the apparent conductivity of products being tested;

— where in-line instrumentation is used, measurement may be skewed by instrument location (especially if SDAs are used).

Based on these considerations a single laboratory conductivity test is not sufficient to establish safe operating limits at loading racks. Therefore, this standard recommends applying a safety factor of at least 2 pS/m to a laboratory-measured conductivity of the product being loaded before applying the guidance in Table 1 and Table 2. (See Annex B.6 for information on conductivity test reproducibility.)

Applying the above safety factor to ultra-low sulfur diesel with a laboratory conductivity measurement of 3 pS/m would indicate the design should take into account product that is between 1 pS/m and 5 pS/m during the course of emptying a tank. Hence to be safe, the more conservative guidance in Table 1 and Table 2 should be applied. Similarly, in situations in which conductivity cannot be verified, the more conservative guidance in Table 1 and Table 2 should be applied. This could result in applying “Ultra Low” operations practices for products known to be “Low Conductivity” (less than 50 pS/m) but not verified as above 2 pS/m at field operating temperature conditions. These factors along with knowledge of the equipment and facility configuration should be taken into account as part of the safety evaluation used to establish precautions needed for specific operations.

4.2 Tank Truck Loading

4.2.1 General

4.2.1.1 Loading Conductive Compartments

A summary of recommended precautions for tank truck loading is provided in Table 1. For a complete discussion of internal coatings, linings, filters and relaxation chambers as they relate to tank trucks, see 4.6.3 and 4.6.6. The following discussions pertain only to conductive (metallic) tank-truck compartments. Nonconductive compartments are discussed in 4.2.12.

4.2.1.2 Initial Loading

Top loading down spouts and bottom loading outlets should be equipped with spray deflectors. Splash filling should be avoided. The liquid velocity in the fill line should be limited to 3 ft/s (about 1 m/s) until the outlet is submerged to prevent spraying and to minimize surface turbulence. (See 4.2.6, 4.2.7, and 4.6.11.) Both the flow in the pipe and the discharge velocity need to be controlled to <3 fps (1 m/s) until the inlet piping is covered. If the pipe is reduced in diameter or split into multiple lines the velocity in each leg needs to be controlled as above.

4.2.1.3 Residence Time

For products with conductivities < 50pS/m a residence time of at least 30 seconds should be provided downstream of filters or wire screens with pore size less than 150 microns (more than 100 mesh/in.). For products with conductivities <2 pS/m, (or where the actual or possible minimum conductivity at field temperature conditions is unknown) a default residence time of 100 seconds should be used. Refer to 4.2.5.6 and 4.6.3.2 for special cases. A waiting period of at least 1 minute should be allowed before a loaded tank compartment is gauged or sampled through the dome or hatch. See 4.2.8 for gauging guidance. Note the difference between relaxation time and residence time in the Section 3 definitions: relaxation time is calculated and residence time is a function of equipment configuration and operating conditions.

Table 1—Summary of Precautions for Tank Truck Loading

	Product Being Loaded			
	Conductivity <50 pS/m (See Definitions)			**Conductivity > 50 pS/m[e]**
Recommended Tank Truck Loading Precaution[a]	Low Vapor Pressure (3.1.12)	Intermediate Vapor Pressure (3.1.11)	High Vapor Pressure (3.1.10)	High Conductivity Products (3.1.5)
1. BONDING—Bonding should be in accordance with 4.2.2. The bond connection should be made before the dome cover is opened and removed only after the dome cover is closed. Bonding may not be required under certain conditions. However, the consistent use of a bonding connection is encouraged to avoid loading mistakes. For top loading, the downspout should form a continuous conductive path and be in contact with the bottom of the tank compartment. (See 4.2.6.)	Yes[b]	Yes	Yes	No
2. INITIAL LOADING—Top loading down spouts and bottom loading outlets should be equipped with spray deflectors. Splash filling should be avoided. The liquid velocity in the fill line should be limited to about 1 m/s (3 ft/s) until the outlet is submerged to prevent spraying and to minimize surface turbulence. (See 4.2.6, 4.2.7, and 4.6.11.) This restriction should be based upon the velocity calculated from the diameter of, and the flowrate through, the tank fill opening and fill line on the tank vehicle itself, not just the loading arm discharge velocity.	Yes	Yes	Yes	Yes
3a. MAXIMUM LOADING RATE—The maximum loading rate should be limited such that the velocity in the down spout, load connection, or discharge velocity does not exceed 7 m/s (23 ft/s) or the value 0.5/d m/s (d = inside pipe diameter in meters), whichever is less. (See 4.2.5.3.) See 3b of this table for ultra-low sulfur diesel (ULSD) loading rate guidance. These flow rate restrictions apply to all piping segments from 0 to 30 seconds (minimum) upstream of the tank fill opening, including the piping segment on the tank vehicle itself. When calculating the vd value in each segment, any flow contributions from other loading arms should be included. If the pipe is reduced in diameter or split into multiple lines the velocity in each leg needs to be controlled as indicated.	Yes[b]	Yes	No[c]	No
3b. MAXIMUM LOADING RATE—The maximum loading rate for ultra low–sulfur diesel and gas oils (<50 ppm S) with conductivity less than 10 pS/m or unknown conductivity should not exceed 7 m/s (23 ft/s or the value 0.38/d m/s (d = inside pipe diameter in meters). The loading rate can be increased to 0.50/d m/s if S > 50 ppm or if the conductivity exceeds 10 pS/m. For tank vehicles that are configured for high-speed loading.[i]	Yes[i]	No	No	No

NOTE All referenced Footnotes appear at the end of Table 2.

Table 2—Charge Relaxation Precautions for Tank Truck Loading with Micropore Filters[h]

	Low Vapor Pressure (3.1.12)	Intermediate Vapor Pressure (3.1.11)	High Vapor Pressure (3.1.10)
Conductivity at transfer temperature (3.1.5, B.6)	**Minimum Residence Time, Seconds**		
General product: conductivity known to be > 50 pS/m	N.A.	N.A.	N.A.
General product: conductivity known to be > 2pS/m but may be < 50 pS/m	> 30 sec[b]	> 30 sec[b]	> 30 sec[f]
General product: conductivity may be < 2 pS/m	> 100 sec[b, g]	> 100 sec[b, g]	> 100 sec[f, g]
Dedicated aviation turbine fuel systems with a successful history handling low conductivity fuels using dedicated trucks and auxiliaries with NO switch loading.	> 30 sec[b]	> 30 sec[b]	N.A.
A waiting period of at least 1 minute should be allowed before a loaded tank compartment is gauged or sampled through the dome or hatch. (See 4.2.8, 4.6.3, and Note d.)			

NOTE Footnotes apply to both Table 1 and Table 2.

[a] Recommended loading precautions vary with the type of 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 “self-service” loading racks), following a single standard procedure that includes all of the precautions is recommended (see 4.2.5.6).

[b] If flammable vapors and mists are avoided, recommended loading precautions need not be applied. This applies when 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. This exemption does not apply when handling low vapor pressure products at temperatures near (within 15 °F to 20 °F [8.5 °F to 11 °C]) or above their flash point, and all specified loading precautions should be followed.

[c] If high vapor pressure products are handled at low temperatures (near or below their flash point) all of the recommended loading precautions should be followed. For consistency, some facilities consider it good practice to maintain the same loading flow rate criteria for all products.

[d] Very low conductivity and high viscosity products may require additional residence time (see 4.2.5.2).

[e] When additives are used to increase conductivity, caution should be exercised (see A.8.5).

[f] The indicated minimum residence time limitation need not apply to existing loading equipment handling only high vapor pressure products. However, it should apply for all new installations regardless of product (see 4.6.3.1).

[g] Where all preventive measures outlined in 4.1.6 of this standard are in place including a ground or bond for spark promoters (e.g. overfill probe) as outlined in 4.2.3, and where documented incident-free experience is available for the specific fuel, conductivity and additive combination, residence time downstream of filters may be reduced to no less than 30 seconds.

[h] Micropore filters include filters or wire screens with pore size less than 150 microns (more than 100 mesh/in.).

[i] For Bottom Loading operations the truck compartment must be equipped with a central conductor consistent with requirements noted in 4.2.7, additionally spark promoters (i.e. gauging rods and other metallic conductors) be extended to the tank bottom as recommended in 4.2.3. If the tank compartment configuration is not consistent with these requirements the maximum allowable loading rate should be 0.25/d m/s for ultra low-sulfur diesel and gas oils (<50 ppm S) with conductivity less than 10 pS/m or unknown conductivity. The loading rate can be increased to 0.38/d m/s if S > 50 ppm or if the conductivity exceeds 10 pS/m.

Where all preventive measures outlined in 4.1.6 of this standard are in place, including a ground or bond for spark promoters (e.g. overfill probe) as outlined in 4.2.3, and where documented incident-free experience is available for the specific fuel, conductivity and additive combination, reduction of relaxation time downstream of filters may be reduced to no less than 30 seconds.

4.2.2 Bonding and Grounding

Top-loaded tank trucks, in which flammable vapors are likely to be present, should be electrically bonded to the downspout, piping, or steel loading rack (see Figure 4). If bonding is to the rack, the piping, rack, and downspout must be electrically interconnected (see 4.2.4). Bonding is usually achieved by means of a bond wire.

The bond connection should be made before the dome cover is opened, and it should remain connected until the dome cover has been securely closed after loading is complete. The bond prevents a build-up of a high electrostatic potential between the fill stem and the tank truck, and it eliminates the likelihood of sparks in the vicinity of the dome opening where a flammable mixture may exist.

Grounding the loading system (i.e. rack, piping, and downspout) in addition to bonding provides no additional protection from electrostatic ignition. Grounding of metallic loading rack components, however, may be necessary for electrical safety (see NFPA 70).

Bonding is essential where high and intermediate vapor pressure products are loaded through open top domes. Bonding should also be employed when loading a low vapor pressure product that is contaminated with a high or intermediate vapor pressure product and when loading low vapor pressure products that are heated above their flash points. Bonding is particularly important when low vapor pressure stocks are loaded into cargo tanks that previously contained high vapor pressure products (switch loading).

Bond wires may be insulated or uninsulated. An uninsulated bond wire permits ready visual inspection for continuity of the bond. Insulated bond wires should be electrically tested or inspected periodically for continuity. The entire bond circuit, including clamps and connectors, should be included in the continuity test. Bond circuit resistance should typically be 1 ohm or less. Resistances less than 10 ohms may function satisfactorily, but test results showing resistances over 1 ohm may be a “warning sign” to prompt further testing or physical examination to ensure that there are no incipient bonding discontinuities (such as a damaged wire, loose connection or paint under a bonding screw). Bond or ground indication instruments are available for installation at truck loading racks to continuously monitor the bond connection. These instruments can be operated in conjunction with signal lights or can be electrically interlocked with the control circuits to prevent the loading pumps from being started when a good bond is not present. Bonding for static control purposes is not required under the following circumstances.

a) When conductive compartments are loaded with products that do not have static-accumulating capabilities, such as asphalt, residual fuels, and most heavy crude oils, and when loading these products is conducted so that mist is not generated. Light crude oils require appropriate precautions based on their properties.

b) When tank vehicles are used exclusively for transporting combustible liquids at a temperature lower than 15 °F to 20 °F (8.5 °C to 11 °C) below their flash point and are loaded at racks where no flammable liquids are handled and mist is not generated.

c) When vehicles are loaded or unloaded through closed connections, irrespective of whether the hose or pipe used is conductive or nonconductive. A closed connection is one in which contact is made before flow starts and is broken after flow is completed [e.g. bottom loading of tank trucks (see Figure 5)].

4.2.3 Spark Promoters

Care should be exercised to avoid spark promoters, such as unbonded conducting objects (i.e. metallic sample cans or loose conductive objects), within a tank compartment.

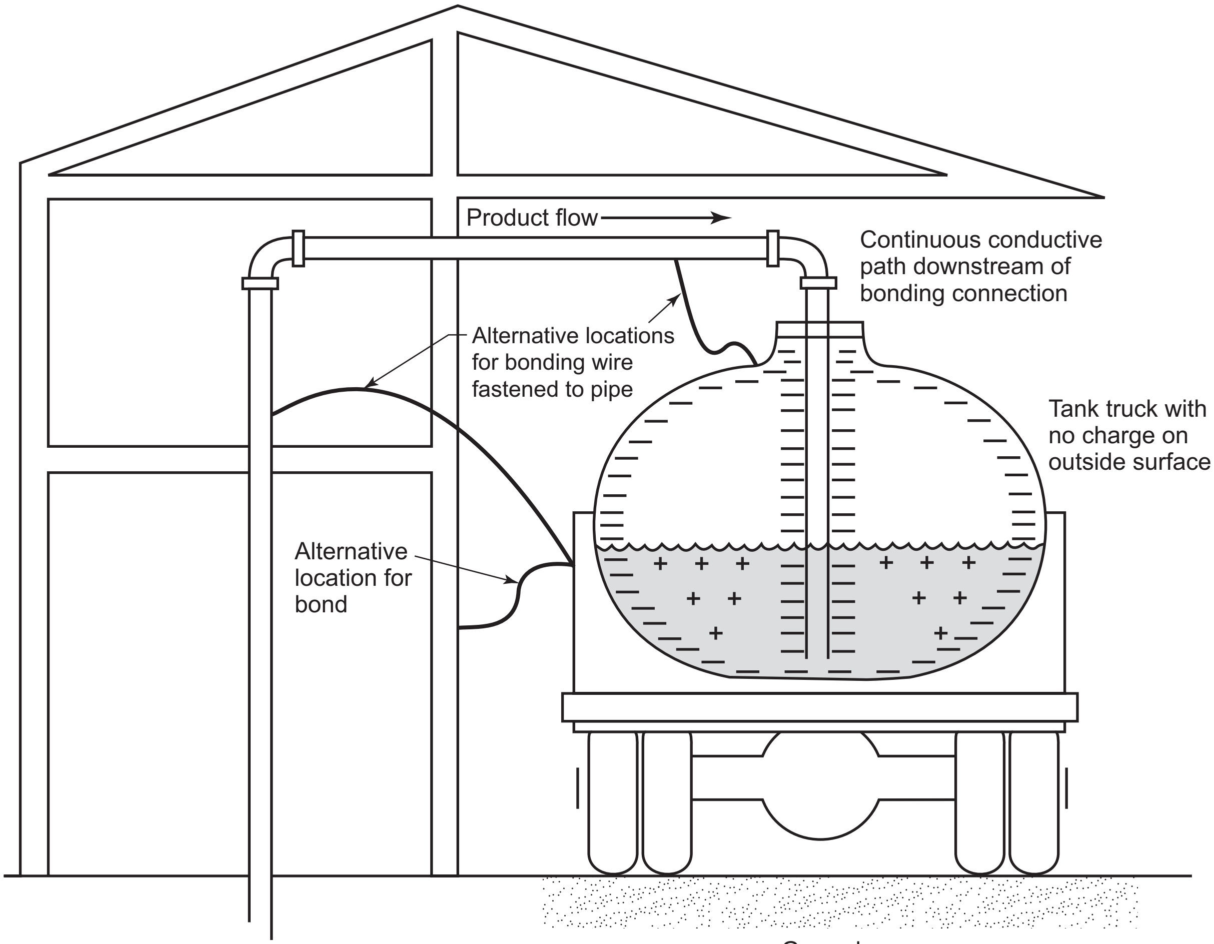


Figure 4—Tank Truck Bonding for Top Loading

A tank gauging rod, high-level sensor, or other conductive device that projects into the cargo space of a tank truck can provide a place for a brush discharge to occur above the rising liquid. If these devices are conductive they should be bonded securely to the bottom of the tank by a conductive cable or rod to eliminate a spark gap, or placed in a gauging well that is bonded to the compartment. Some high-level sensors currently on the market are not designed to accommodate a bonding cable or rod. In these situations, a bonding rod or cable could be installed immediately adjacent to the sensor, or place the device in a gauging well. Chains historically have been used for bonding conductive projections, but their use is not recommended since a conductive path cannot be guaranteed. Periodic inspection should be conducted to ensure that bonding cables do not become detached. If these devices are nonconductive, the above measures are not required.

In a normal top loading operation the downspout extending into the liquid is conductive and at ground potential (see Figure 4). If the downspout is near a projection, the voltage gradient on the liquid surface near the projection may be reduced enough to diminish the possibility of static discharge. However, it is difficult to define the minimum distance to ensure that an incendive spark will not occur. Therefore, the use of bonding or a gauge well as described above is preferred. See 4.2.8 for a discussion of sampling and gauging.

4.2.4 Continuity of Fill Line

For open-dome top loading, all metallic parts of the downspout assembly should form a continuous, electrically conductive path downstream of the bond connection (see Figure 4). The connections for a metallic fill-pipe assembly generally form a continuous, electrically-conductive path, and bond wires are not normally needed around flexible,

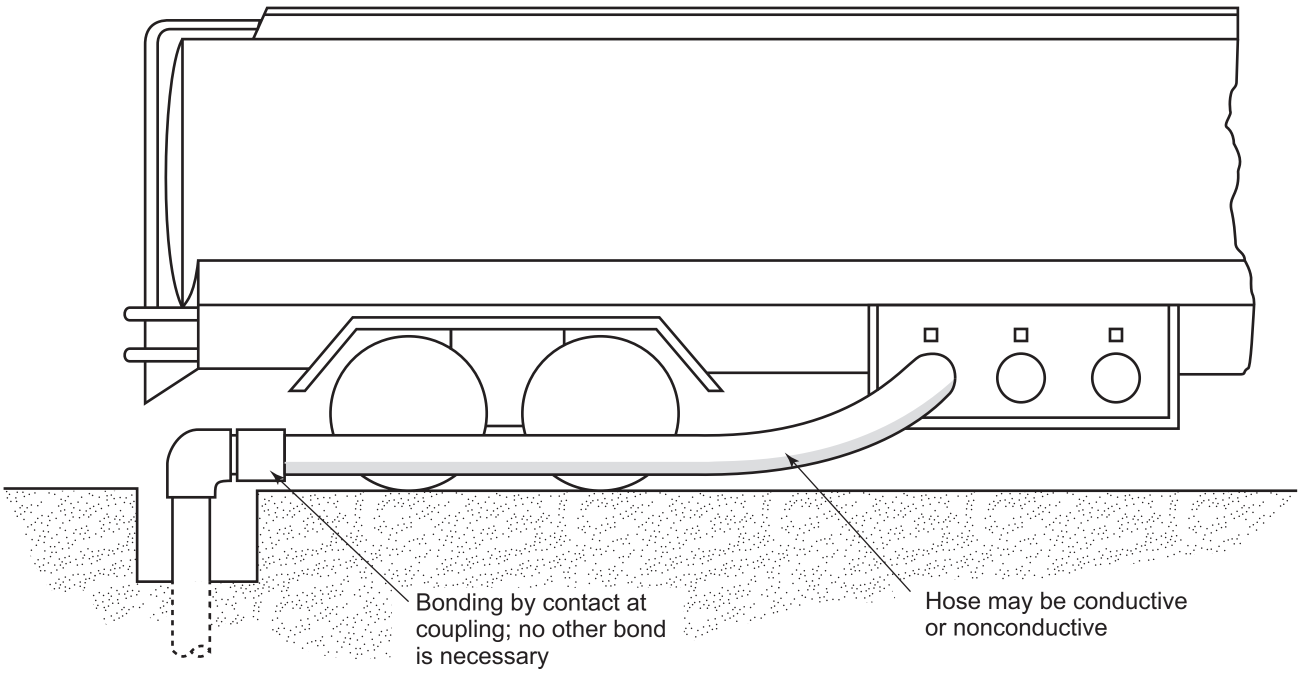


Figure 5—Loading and Unloading of Tank Trucks Through Closed Connections

swivel, or sliding joints. Tests and experience have shown that resistances in these joints are normally under 10 ohms, low enough to prevent accumulation of static charges. However, it is wise to check the manufacturer's specifications on such joints because a few are fabricated with insulated surfaces. In addition, there have been cases where swivel or sliding joints have deteriorated in service and the resistance increased to the point where they did not provide an adequate conductive path. Although not considered necessary by most operators, some users do install straps across swivel joints as an additional protective measure.

When hoses are used the coupling must be bonded to the fill line and to the compartment being filled so as to form a continuous conductive path. For hoses with embedded bonding wire, the electrical continuity of a hose assembly should be tested prior to and monitored during use.

Overall, to prevent incidents, test the resistance of the complete fill-pipe or hose assembly, particularly those that include swivel/sliding joints, at least annually. In verifying an adequately low resistance, care must be taken to test the fill-pipe or hose assembly at different swivel/sliding joint positions.

Electrical continuity in the filling connection assembly is not required for static control purposes in pressurized-system loading, such as LPG loading.

Electrical continuity is also not required in bottom or top loading through closed truck connections to protect against internal discharges. However, if there are ungrounded metal parts in the filling connection there may be a hazard created by external sparking (e.g. metal flanges between two sections of nonconductive hose).

4.2.5 Control of Electrostatic Charge Generation

4.2.5.1 General

Bonding and grounding provide no protection from brush discharges generated from the surface of a low conductivity liquid, particularly if there is a spark promoter present. Fuel conductivity is discussed in A.5 of Annex A. The conductivity of many refined petroleum products can be well below 50 pS/m, and accumulation of electrostatic charge is likely. Charge accumulation is even more likely for ultra-low conductivity (less than 2 pS/m) hydrocarbons. Spark promoters are discussed in 4.2.3.

The following four primary electrostatic charge generation mechanisms relate to tank truck filling operations:

1) product flow through filters and screens;

2) product flow through piping;

3) splash loading; and

4) multiphase flow.

4.2.5.2 Flow-through Filters and Screens

Flow-through filters and screens can produce a high electrostatic charge. The degree of hazard depends on the size of the openings within the filter or screen. In general, when product conductivity is less than 50 pS/m an adequate residence time should be provided downstream of the filter or screen to permit sufficient charge relaxation. See 4.6.3 for a comprehensive discussion of electrostatic issues relating to filters and screens. The need for residence time for charge relaxation increases as the conductivity decreases.

4.2.5.3 Flow-through Piping

Precautions involving flow velocity are required only for intermediate vapor pressure products, for switch loading and for special situations where flammable vapors may be present (see 4.1.5).

The flow of liquid through piping generates static charge (see Annex A.2). The magnitude of the charge is a complex function of a fluid's composition and the rate of product flow. A simple empirical formula relating the maximum recommended linear velocity to minimize charge generation as a function of loading arm diameter has been developed for tank trucks. (The unfamiliar units of in.-ft/s result from using the internal pipe diameter in inches and flow rate in ft/s.)

$$vd < 0.5 \text{ m}^2\text{/s (64 in.-ft/s)}$$

where

v is velocity in m/s (ft/s);

d is inside diameter of the downspout in meters (in.).

Flow rates and velocities that meet this limit are shown in Table 3 for selected pipe sizes. (See Figure 6 for the conversion chart associated with Table 3.) In addition, linear flow velocity should never exceed 23 ft/s (7 m/s). These flow rate restrictions apply to all piping segments from 0 to 30 seconds (minimum) upstream of the tank fill opening, including the piping segment on the tank vehicle itself. When calculating the vd value in each segment, any flow contributions from other loading arms should be included.

The 64 in.-ft/s (0.5 m^2/s) limit does not ensure that static ignition will not occur, but it greatly reduces the probability of ignition. Industry experience loading ULSD has indicated that the historical limit of 64 in.-ft/s (0.5 m^2/s) may not be adequately protective. For tank trucks loading ULSD and Gas oil. The maximum flow rate should never exceed 23 ft/s (7 m/s) or 0.38m^2/s whichever is greater. See Table 3.

NOTE When incidents have occurred investigations have shown that precautions were not followed or other factors were present such as low residence time after filters, splash filling, and improper bonding and grounding (see 4.2.5.6).

Table 3—Velocities and Flow Rates for Schedule 40 Pipe

Nominal Pipe Size (in.)	Inside Diameter		Flow Velocity			Flow Rate	
	in.	mm	ft/s	m/s	*vd* Constant (Sq. m/s)	gal/min.	L/min.
1 1/2	1.610	40.9	3.28	1.0	—	21	79.5
			22.97	7.00	0.286	146	553
2	2.067	52.5	3.28	1.00	—	34	129
			22.97	7.00	0.368	240	908
3	3.068	77.9	3.28	1.00	—	76	288
			15.65	4.77	0.38	360	1364
			22.97	7.00	0.54	529	2002
4	4.026	102.3	3.28	1.00	—	130	492
			11.92	3.63	0.38	473	1791
			16.04	4.89	0.5	637	2411
			22.97	7.00	0.72	911	3448
5	5.047	128.2	3.28	1.00	—	205	776
			7.91	2.90	0.38	539	2041
			12.79	3.90	0.5	798	3020
			20.5	6.20	0.8	1277	4833
6	6.065	154.1	3.28	1.00	—	295	1117
			7.91	2.41	0.38	713	2697
			10.64	3.24	0.5	959	3630
			17.00	5.20	0.8	1539	5825
8	7.981	202.7	3.28	1.00	—	512	1938
			6.01	1.83	0.38	938	3550
			8.09	2.47	0.5	1260	4769
			12.95	3.90	0.8	2018	7638
10	10.020	254.5	3.28	1.00	—	806	3051
			4.79	1.46	0.38	1177	4456
			6.44	1.96	0.5	1580	5980
			10.31	3.14	0.8	2536	9599
12	11.938	303.2	3.28	1.00	—	1140	4315
			4.00	1.22	0.38	1410	5337
			5.41	1.65	0.5	1890	7154
			8.66	2.64	0.8	3020	11431

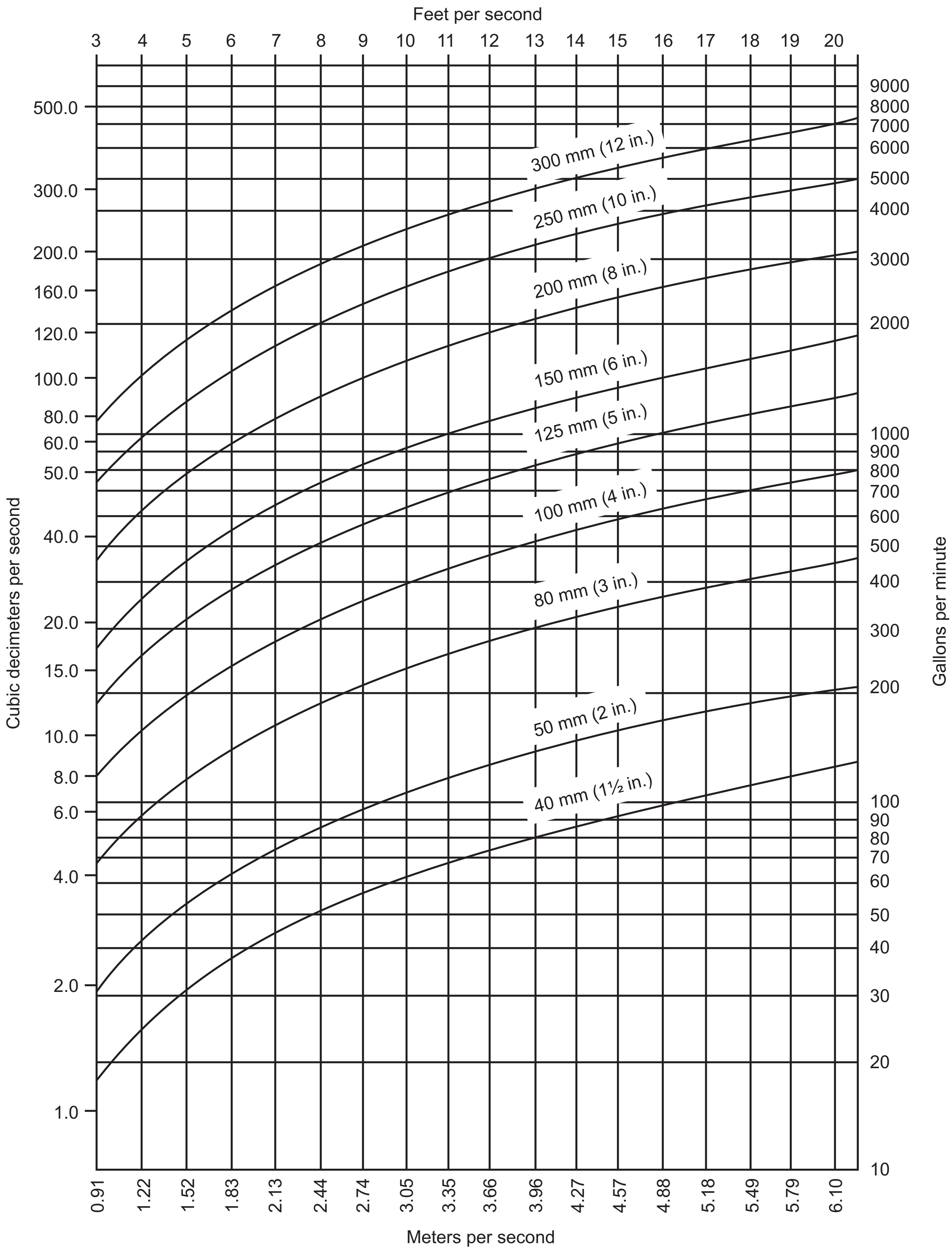


Figure 6—Conversion Chart for Flow Rates and Velocities for Selected Pipe Sizes

4.2.5.4 Splash Loading

The third charge generation mechanism important in tank truck loading is splash loading. In this instance, the electrostatic charge is generated in the liquid by turbulence and by the generation of a charged mist (see 4.6.11). Splash filling should be avoided to minimize turbulence and mist generation. See 4.2.6 and 4.2.7 for specific measures depending on loading method.

4.2.5.5 Multi-phase Flow

Multi-phase flow generates electrostatic charge both as a result of both flow through piping (where the presence of multiple phases enhances several-fold the charge generation potential of pipe flow) and also when the different phases settle in the tank compartment. Therefore, whenever the fluid is a static accumulator and contains a dispersed phase, such as entrained water droplets, the inlet flow velocity should be restricted to 1 m/s (3 ft/s) throughout the filling operation. In addition, a suitable waiting period should be employed to allow for product charge relaxation before any object such as temperature gauge or sample container is lowered into the tank compartment (see 4.2.8).

4.2.5.6 Risk Management

Studies (see Bibliography items 14 through 17) have estimated that the frequency of static related tank truck loading ignitions is very low and the incidents that have occurred involved either the loading of an intermediate vapor pressure product or switch loading (see 4.1.5.2. In most of these ignitions, the cause of the incident was attributed to the failure to follow recognized procedures and guidelines. The following specific risk factors can be identified:

a) fluid conductivity less than 2 pS/m;

b) flow velocity at or close to the maximum allowed;

c) residence time after filters/screens at or slightly below the minimum recommended;

d) presence of a significant turbulence generator that is close to the compartment inlet (i.e. partly open block valves, etc.).

If one or more of these conditions are expected at a facility where intermediate vapor pressure products are loaded or switch loading is performed, consideration should be given to preventive measures that exceed those outlined in this publication (see 4.1.6 for examples of preventive measures). For example, a further reduction in flow velocity could be employed, conductivity additive could be used, switch loading could be eliminated, or the waiting period could be increased.

4.2.6 Top Loading with Downspouts

Splash loading can contribute to the generation of electrostatic charges. Therefore, during open-dome top loading of intermediate vapor pressure products or switch loading of low vapor pressure products, a conductive downspout should reach to the bottom of the tank and should preferably be in contact with the bottom to avoid undue turbulence. However, the downspout should not rest “full circle” on the bottom. A “T” deflector or a 45-degree bevel should be used on the end of the downspout. If a deflector is used, it should be designed to prevent the downspout from lifting off the tank bottom when flow starts.

The initial velocity in the downspout and at the discharge point should be limited to about 3 ft/s (1 m/s) until the downspout outlet is submerged by at least two downspout diameters. The flow rate can be increased within the limits specified in 4.2.5.3. Loading velocities can be controlled by using a flow control valve that automatically limits the initial velocity to about 3 ft/s (1 m/s).

Discharging petroleum liquid freely from a hose into a tank truck during top loading is not recommended. If such an operation is unavoidable, the following minimum precautions should be met:

a) all metal fittings (including hose weights) should be bonded to the tank;

b) the hose should be secured during loading to prevent movement;

c) splash filling should be avoided by inserting the hose to the bottom of the compartment;

d) loading velocity restrictions should be followed.

4.2.7 Bottom Loading

Bottom loading minimizes the possibility of electrostatic hazards that could result from improper bonding or positioning of the downspout in top loading. However, in the initial stages of bottom loading, upward spraying of the product can increase charge generation and should be prevented by reducing the filling velocity and using a spray deflector or other similar device. If bottom-loading inlets in tanks are not designed to avoid spraying, low vapor pressure products can form an ignitable mist. The initial velocity in the fill line and discharge point should be limited to about 3 ft/s (1 m/s) until the fill line outlet and deflector (when provided) is submerged by at least two fill line diameters. The submergence requirements can be reduced if it is demonstrated that no spraying occurs. This restriction should be based upon the velocity calculated from the diameter of, and the flow rate through, the tank fill opening and fill line on the tank vehicle itself, not the loading arm.

Bottom-loading rates should comply with the flow restrictions described in 4.2.5.3.

Bottom loading may result in higher liquid surface voltages than top loading due to the ability of the downspout to reduce the surface voltage and sparking. A central conductor such as a cable or rod at least 0.08 in. (2 mm) in diameter positioned near the center of the compartment and connected from the roof to the bottom of the tank will also serve the same purpose. With bottom loading, it is especially important that spark promoters (i.e. gauging rods and other metallic conductors) be extended to the tank bottom, as recommended in 4.2.3.

4.2.8 Sampling and Gauging

Sampling and gauging operations can introduce spark promoters into the tank, increasing the likelihood for a static discharge. During tank truck filling operations an electrostatic charge can accumulate on the product due to various charge generation mechanisms (see 4.2.5). Where a flammable atmosphere can be expected in the vapor space of a tank compartment, metallic or conductive objects such as gauge tapes, sample containers, and thermometers should not be lowered into or suspended in the compartment either during or immediately after loading of product. Depending on the size of the compartment and the conductivity of the product being loaded, a sufficient waiting period should be employed to permit the product charge to dissipate (charge relaxation).

A 1-minute waiting period is recommended before gauging or sampling tank compartments, regardless of the conductivity of the device being used. Longer waiting periods may be appropriate for very low conductivity liquids, such as very clean solvents and chemical-grade hydrocarbons, or multi-phase mixtures.

Conductive sampling and gauging devices should not be used with a nonconductive lowering device (handle, cable, rope, rod, etc.). Conductive sampling and gauging devices (including the sampling container and lowering device) should be properly bonded to the tank compartment or truck. Such bonding should be accomplished by use of a bonding cable or by maintaining continuous contact between the lowering device and the tank hatch.

It should be noted that nonconductive sampling and gauging devices might not retain the necessary high degree of insulation due to environmental factors such as moisture or contamination.

The use of synthetic fiber (nylon and polypropylene) ropes is not recommended. Tests have shown that when synthetic ropes rapidly slip through gloved hands for appreciable distances, such as into large tanks, an insulated person can become charged. Natural fiber ropes should be kept in continuous contact with the tank hatch because they may be conductive if not kept clean and dry.

4.2.9 Highway Transport

Normal highway conditions create no static hazard in compartmented or baffled tank trucks. However, several explosions in partially filled, clean-bore (unbaffled) tank trucks during highway transport have been attributed to static generated by splashing of surging liquid during acceleration and deceleration of the vehicle. Hence, intermediate vapor pressure products or products subjected to switch loading should not be transported in unbaffled tank trucks.

4.2.10 Vapor-balanced Tank Trucks and Vapor Recovery

During loading of vapor-balanced compartments, the same precautions taken during loading of compartments vented to the atmosphere should be observed.

In addition, it is not safe to assume that the presence of a vapor recovery system will ensure a safe atmosphere within the tank truck compartments. When different vapor pressure products are being loaded using a common vapor recovery system, a flammable atmosphere may be introduced into the compartments. Such systems should be carefully reviewed to determine whether this hazard is significant at the particular facility. If the hazard is judged to be significant the facility can use the same control measures used for switch loading.

Isolated conductive sections should be avoided in vapor recovery lines. All conductive parts of the vapor connection on the tank vehicle should be in electrical contact with the cargo tank. Liquid cascading from one compartment to another as a result of overfilling through the common overhead system can create electrostatic and other hazards.

4.2.11 Unloading

Neither the unloading of tank trucks through open domes by means of suction pipes nor closed system unloading from fixed top or bottom outlets require protection against static sparks. However, the receiving vessel may require electrostatic protection, as may the suction pipe in open-dome unloading if the pipe is conductive and not grounded.

Bonding between tank trucks and underground service station tanks during delivery of product to the tanks is not required provided the hose nozzle is maintained in metallic contact with the grounded tank fill pipe or tight connections are used between the hose and the tank fill pipe. If the tank is nonconductive (i.e. fiberglass) supplemental grounding may be required for the fill pipe. Experience indicates that no static ignition hazard is present during this operation when these precautions are followed.

4.2.12 Nonconductive Compartments and Linings

When tank-truck compartments are constructed of a nonconductive material such as fiberglass reinforced polyester (FRP) rather than metal, the following electrostatic concerns should be considered:

a) the electrostatic field is not confined to the interior of the compartment; hence, an electrostatic discharge could occur external to the tank or in an adjacent compartment;

b) there is no efficient means for charge dissipation from the fluid; hence, the probability of an internal discharge is increased.

Where it is unavoidable to transport static accumulators in tank trucks with nonconductive compartments and a flammable atmosphere may be present within the compartment or in the immediate vicinity, tests indicate that to ensure the safe dissipation of charge and prevent discharges, all the following features should be incorporated.

1) All conductive components (e.g. a metal rim and hatch cover) should be bonded to the truck chassis.

2) An enclosing conductive shield bonded to the truck chassis should be provided to prevent external discharges. This shield may be in the form of a wire mesh buried in the compartment wall that is bonded to the truck chassis, as long as the chassis is grounded during filling. The shield should include all external surfaces: both the cylindrical shell and end-caps. In addition, if the tank is divided into compartments, each bulkhead should contain a shield bonded to the chassis.

3) Each tank truck compartment should have a metal plate surface area not less than 30 in.^{2}/100 gal (194 cm^2/379 L) located at the compartment bottom and bonded to the truck chassis. This plate provides a conductive path between the liquid contents and ground.

Truck compartments with all these features can be safely filled using the same procedures as needed for metal tank compartments in the same service.

For tank truck compartments with a nonconductive lining, see 4.6.6.

4.2.13 Tank Vehicle Inspection Criteria

Owners of tank trucks and tank cars should have a process to inspect for the following conditions and to correct any deficiencies. Inspections should be done on a routine basis (at least annually) and include at least the following items:

a) ensure that conducting objects such as loose floats or screens are properly bonded or removed;

b) ensure that measures are in place to prevent gauging rods and other conductive devices from becoming spark promoters (see 4.2.3);

c) ensure that the spray deflector, required for bottom loading, is properly installed (see 4.2.7);

d) check for damage to internal tank baffles;

e) ensure that grounding systems are working properly;

f) ensure that bond connections are not broken or corroded.

Owners of tank truck loading facilities should require that the carriers have an inspection process in place.

4.3 Tank Car Loading

4.3.1 General

For a complete discussion of internal coatings, sampling and gauging, and filter and relaxation chambers as they relate to tank cars, see 4.6.6, 4.2.8, and 4.6.3, respectively.

4.3.2 Bonding and Grounding

Many tank cars are equipped with nonconductive bearings and nonconductive wear pads located between the rail car and chassis. As a result, the resistance from the tank car compartment to ground through the rails may not be low enough to prevent the accumulation of an electrostatic charge on the tank car body. Therefore, bonding of the tank car body to the fill system piping is necessary for protection against static accumulation.

In addition, because of the possibility of stray currents and to prevent an ignition hazard as a result of such currents, loading lines should be bonded to the rails (see Figure 7). See 6.3.2 for details regarding protection against stray currents.

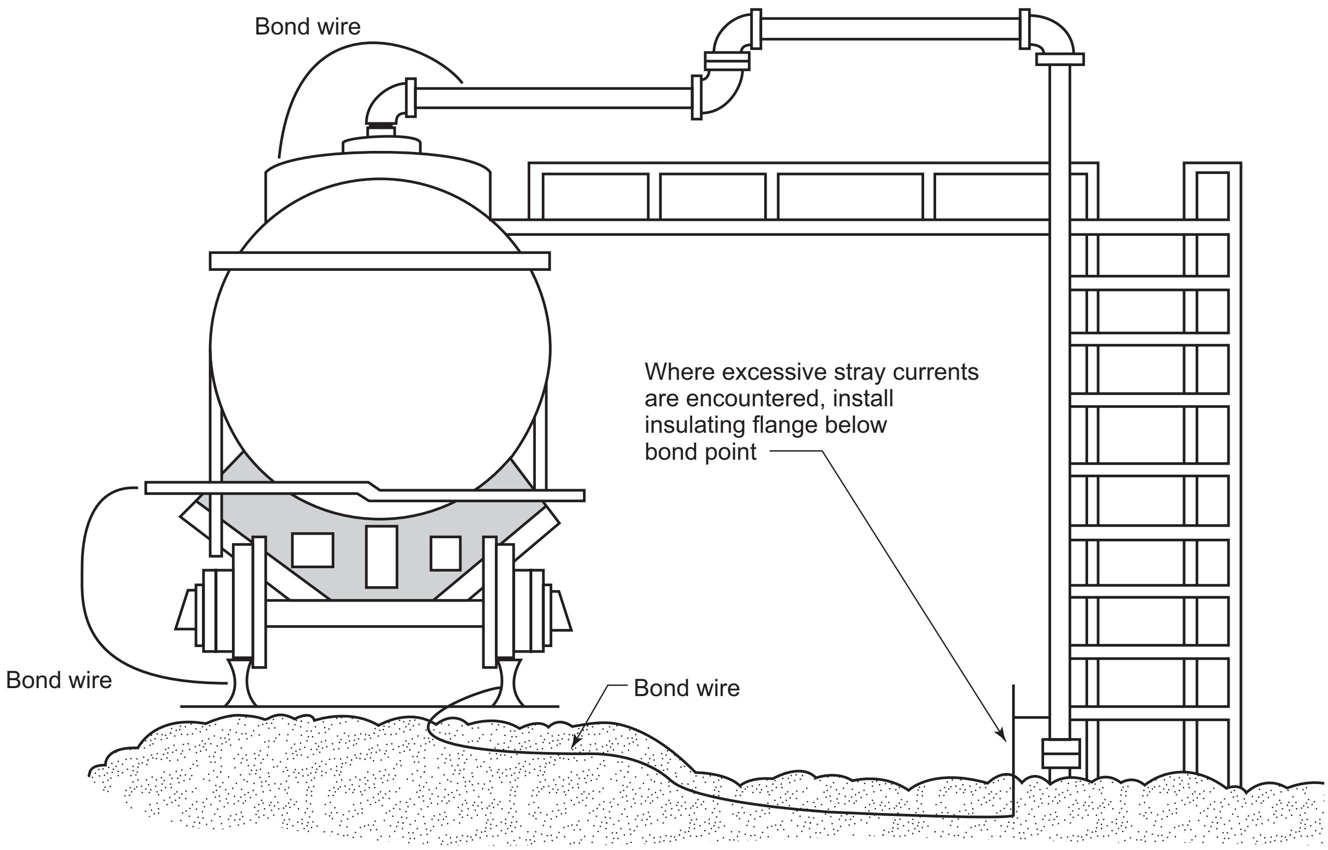


Figure 7—Tank Car Bonding

4.3.3 Spark Promoters

See 4.2.3 for discussion of spark promoters.

4.3.4 Continuity of Fill Line

All metallic parts of the fill-pipe assembly for top-dome loading should form a continuous, electrically-conductive path downstream of the point of the bond connection to the rails (see Figure 7). Within the downstream portion of the piping, the same considerations that are pertinent to tank truck fill lines apply (see 4.2.4).

4.3.5 Control of Electrostatic Charge Generation

When flammable mixtures can be expected in the tank car vapor space and the products involved may have conductivity less than 50 pS/m, the precautions for loading tank trucks described in 4.2.5 should be followed, with the exception of a revised empirical formula:

For flow-through piping, the maximum recommended linear velocity to minimize charge generation is given by the following empirical formula:

$$vd < 103 \text{ in.-ft/s } (0.8 \text{ m}^2\text{/s})$$

where

v is velocity, in ft/s (m/s);

d is inside diameter of the downspout, in inches (meters).

A higher vd value is allowed for tank cars than for tank trucks because the tank geometry and size reduces the electrostatic field. Flow rates and velocities that meet the 0.8 limit are shown in Table 3 for selected pipe sizes.

In addition to this restriction, linear flow velocity should never exceed 23 ft/s (7 m/s).

4.3.6 Top Loading with Downspouts

See 4.2.6 for a discussion of top loading with downspouts.

4.3.7 Bottom Loading

See 4.2.7 for a discussion of bottom loading.

4.3.8 Sampling and Gauging

See 4.2.8 for a discussion on sampling and gauging.

4.3.9 Unloading

See 4.2.11 for a discussion of unloading.

4.3.10 Tank Car Inspection Criteria

See 4.2.13 for a discussion of tank vehicle inspection.

4.4 Marine Operations

As with onshore operations, handling petroleum products in marine operations presents potential for fire and explosion hazards due to static electricity. The principles and practices in API 2003 should be applied when loading static accumulator cargoes on tanker ships and barges.

Extensive static electricity precautionary guidance for oil tankers is provided by the OCIMF *International Safety Guide for Oil Tankers and Terminals (ISGOTT)*. *ISGOTT* addresses oil tankers. U.S. Coast Guard regulations require oil tankers to be fitted with Inert Gas Systems (IGS) and chemical tankers with large tanks and high-capacity tank cleaning machines must also be fitted with IGS. Some vessel operators voluntarily install IGS on barges and chemical tankers. U.S. Coast Guard rules and *ISGOTT* require the use of these inert gas systems while loading, unloading, sampling, gauging, and tank cleaning. IGS use provides risk reduction while enabling use of less constraining operating procedures.

NOTE All references in this publication to *ISGOTT* refer to the 2006, 5th Edition.

ISGOTT guidance on static hazards primarily addresses operations on non-inerted oil tankers where the precautionary principles of *ISGOTT* and this standard should be applied. Subsequent requirements in this section for tankers and barges will be based on whether or not the particular vessel is fitted with (and using) IGS.

4.4.1 Loading Velocity Flow Control

Whether for land or marine operations, API 2003 specifies special attention to control of flow velocities in the entire piping system. Whether inerted or not, *ISGOTT* Section 11.1.6.7 states "The initial flow should be at a slow rate. Whenever possible this should be by gravity and to a single tank..." Section 11.1.7.3 recommends a maximum initial filling velocity of 1 m/s in each branch line. This standard seeks to satisfy this limit wherever the highest flow velocity occurs (typically the smallest cross-sectional area including valves or other piping restrictions). The goal is to ensure that the initial and bulk loading velocity limits are not exceeded even in the fastest flowing lines. API 2003 recommends that where possible the flow rate maximum limit be applied throughout the entire fill line system from the shore connections until the product exits the piping and enters the cargo holds of a tanker or barge.

Residence times, calculated from system configuration, should be maintained upstream of the tank inlet(s) during loading for the minimum time which satisfies needs based on conductivity of the liquid flowing. As indicated in the next paragraph the minimum residence time is at least 30 seconds and for some ultra-low conductivity cargos, the minimum time should be increased to 100 seconds. Only grounded piping can be used in calculating residence time. If sections of non-conducting hoses are used for isolating a vessel from shore that section shall be excluded from the residence time calculation.

The following flow management guidance from 4.1.6 should be used in marine as well as land-based operations:

— "limit initial fill rates and maximum flow rates (e.g. in filling operations);"

— "control hydrocarbon flow velocities in all applicable piping segments;" and

— "use sufficient residence time downstream of pumps and filters."

Residence times recommended depend on the electrical conductivity of the material being loaded.

— For products with conductivities >2 pS/m and <50 pS/m a residence time of at least 30 seconds should be provided downstream of filters or wire screens with pore size less than 150 microns (more than 100 mesh/in.).

— For products with conductivities <2 pS/m (or where the actual or possible minimum conductivity at field temperature conditions is unknown), a residence time of at least 100 seconds should be provided.

As for land-based tanks a waiting period of at least 30 minutes should be allowed after flow has ceased before a loaded tank compartment is gauged or sampled through the dome or hatch (see 4.5.6.2 and *ISGOTT* Section 11.8.2).

Section 6.3.3 of this RP addresses protection against stray currents at wharfs and notes the need for electrical isolation of the vessel from shore on both loading and vapor recovery lines while maintaining proper bonding on each side of the isolation.

4.4.2 Inerted Vessels

When a tank is known to be in an inerted condition, no antistatic precautions are necessary (see *ISGOTT* 11.1.7.2). The USCG specifies that unless the cargo tanks are gas free, inert gas systems shall be operated as necessary to maintain an inert atmosphere in the cargo tanks.

If the function of an inert gas system is "unknown" then the precautions in 4.4.4 for non-inerted vessels shall be followed.

4.4.3 Non-inerted Vessels

4.4.3.1 General

Non-inerted oil tankers, barges and chemical tankers should apply the *ISGOTT* precautions for handling static accumulator cargos.

The following minimum practices in this recommended practice include the following.

1) The 3 ft/s (1 m/s) maximum initial fill rate should be applied to all piping segments for the applicable residence time upstream of the cargo tank inlet.

2) Residence times in 4.4.2 of this recommended practice should be applied.

3) Implement the *ISGOTT* risk assessment approach to reduce risk for loading products with static accumulation potential where vessel configuration and potential uncertainty regarding equipment size and operator experience are factors. Risk assessment is especially appropriate where there is uncertainty regarding the electrical conductivity characteristics of the product being loaded or the properties of the prior cargo.

As referenced above, *ISGOTT* Sections 11.1.7.3 and 11.1.7.4 provide recommendations of 3 ft/s (1 m/s) maximum initial fill and 23 ft/s (7 m/s) maximum bulk loading line velocities which agree with this recommended practice. The surveillance and calculation approach outlined in 11.1.7.4 for bulk loading limits velocity in the smallest diameter hoses or piping which have the highest velocity at a given flow rate. This approach should also be applied during initial loading for both individual and “spread loading” to provide protective velocity control throughout the system for all flow elements. Section 4.4.2 residence times before discharge should be applied.

4.4.3.2 Individual Cargo Tank Loading for Non-inerted Vessels

Both API 2003 as well as *ISGOTT* are consistent in applying the 3 ft/s (1 m/s) initial and 23 ft/s (7 m/s) bulk loading rates for non-inerted vessels. If these cannot be achieved, then the *ISGOTT*-defined risk assessment and 4.4.4.3 risk reduction recommendations should be reviewed.

4.4.3.3 Spread Loading Non-inerted Vessels

ISGOTT spread loading provisions are intended for non-inerted tankers and barges The *ISGOTT* 11.1.7.7 guidance for spread loading (Loading Multiple Tanks Through a Common Manifold) states “The management of risks inherent in spread loading will require a risk assessment process to be followed.” In addition to the *ISGOTT* guidance, recommendations from RP 2003 (such as observing appropriate residence time as a function of conductivity) should be considered when conducting the risk assessment and subsequent risk analysis. *ISGOTT* Section 11.1.7.7 concludes with “Spread loading should only be carried out when the ship and the terminal are both satisfied that the risks have been identified and that appropriate risk response measures have been taken to minimize, avoid or eliminate them.”

Spread loading should only be considered where the vessel configuration is known and expertise is available to perform the surveillance, and calculation outlined in *ISGOTT* Section 11.1.7.4 is available. If this knowledge and expertise is not available, then spread loading should not be used without additional risk reduction measures being implemented.

ISGOTT emphasizes the importance of achieving the specified initial fill velocity limit of 3 ft/s (1 m/s). *ISGOTT* Section 11.3.3.2 also cautions “*the maximum loading rate may be determined by the flow rate through the manifold or drop lines. For this reason, it is important that a constant check is kept on the number of cargo tank valves that are open simultaneously and that a suitable loading rate is determined for the particular loading operation. The maximum allowable volume flow rate should keep flow velocity in all lines from exceeding the maximum allowable for each individual line*.” If fill velocities cannot be kept below the allowable 1 m/s maximum initial fill and 23 ft/s (7 m/s) maximum bulk loading line velocities then analysis of the risk assessment should consider using additional risk reduction techniques such as those described below.

Alternative risk reduction measures include one or more of the following:

— inerting cargo tanks with a system other than an IGS prior to loading a static accumulator cargo;

— establishing an atmosphere less than 10 % LEL prior to switch loading operations (strip, clean and/or ventilate cargo tanks as necessary);

— transporting static accumulator products only in vessels dedicated to carriage of cargos with a flash point greater than 125 °F (51 °C); or

— injecting an SDA in the product prior to loading.

4.4.4 Bonding and Grounding for Marine Operations

Section 6.3.3 addresses bonding and protection against stray currents at wharfs. A static precaution of special significance for marine vessels is electrical isolation of the shore side from the vessel (*ISGOTT* Section 17.5). Both the loading line (*ISGOTT* Section 3.2.2) and vapor recovery lines (*ISGOTT* Section 11.1.13.8) are required to use either insulating flanges or nonconductive hose to achieve isolation. As noted in *ISGOTT* Section 3.3.2, grounding on the vessel side is achieved through connecting to the hull while on the shore side bonding and grounding are through conventional means. A ship/shore bonding cable does not replace the requirement for an insulating flange or hose as described above (*ISGOTT* Section 5 17.5). The use of ship/shore bonding cables may be dangerous and should not be used (*ISGOTT* Section 5 17.5.4).

4.5 Storage Tanks

4.5.1 General

Although infrequent, static discharge incidents have occurred in atmospheric storage tanks. Charge generation phenomena for tanks are the same as discussed in earlier sections. High flow results in charge separation. Controlling flow below 3 ft/s (1 m/s) reduces this hazard by allowing time for charges to dissipate through piping. Switch loading introduces the hazard of flammable vapors in an environment where there can be charge generation. If oxygen is available (vented cone-roof tanks and floating roof tanks resting on legs) this additional hazard increases the risk. Minimizing static charge accumulation reduces the risk by reducing the probability of a static discharge.

For a discussion of ignition due to static electricity, spark promoters, and flammable vapor-air mixtures, see 4.1.3, 4.1.4, and 4.1.5, respectively. For a discussion of precautions relating to internal coatings, and filters and relaxation chambers, see 4.6.6 and 4.6.3, respectively.

The following discussion pertains only to conductive (metallic) storage tanks. Nonconductive tanks are discussed in 4.5.9.

4.5.2 Control of Electrostatic Charge Generation

The possibility of a static discharge between the liquid surface and the tank shell, roof supports, or other appurtenances is related to the static-generating qualities of the liquid in the tank. The generation rate is also influenced by the degree of turbulence in the liquid and by the settling of minute quantities of finely divided materials, such as water droplets, particles of iron scale, and sediment. The possibility of a spark is greater in the presence of a spark promoter (see 4.1.4 and Figure 1 and Figure 2).

Refined petroleum products that tend to retain static charges can introduce a greater risk of static ignition unless they are handled properly. Protective measures should be used when the vapor space in a storage tank is likely to contain flammable mixtures such as:

— intermediate vapor pressure products;

— low vapor pressure products contaminated with high vapor pressure liquids;

— low vapor pressure products that contain dissolved hydrogen or light hydrocarbon from the treating process or switch loading.

Protective measures may include the following.

a) Avoiding splash filling and upward spraying. The fill-pipe outlet should discharge near the bottom of the tank, with minimum agitation of the water and sediment on the tank bottom. Where the outlet of the fill line is attached to a "downcomer," the siphon breakers that permit air or vapor to enter the downcomer should not be used. Avoid discharging the product from a nozzle that is elevated above the liquid level.

b) Limiting both the fill line and discharge velocity of the incoming liquid stream to 3 ft/s (1 m/s) until the fill pipe is submerged either two pipe diameters or 2 ft (61 cm), whichever is less. In the case of a floating-roof (internal or open-top) tank, observe the 3 ft/s (1 m/s) velocity limitation until the roof becomes buoyant. Static charges accumulated in the upstream piping can be carried with the product into the tank. The flow rate restrictions apply to all piping segments from 0 to 30 seconds (minimum) upstream of the tank fill opening, including the piping segment on the tank itself. This controlled velocity cannot be satisfied by placing a "tee" at the discharge to reduce final discharge flow rates. During the initial stages of tank filling more opportunity exists for the incoming stream to produce agitation or turbulence, hence the need to limit the inlet velocity. However, the product's flow rate should be kept close to 3 ft/s (1 m/s) during this period, since lower velocities can result in settling out of water at low points of piping. Subsequent re-entrainment when the velocity is increased could significantly raise the product's charging tendency.

c) Where the material is a static accumulator and contains a dispersed phase, such as entrained water droplets, the inlet flow velocity should be restricted to 3 ft/s (1 m/s) throughout the filling operation (see 4.2.5.5).

d) Provide a minimum 30 second residence time downstream of Micropore filters (see 4.2.5.2 and 4.2.5.6).

e) Check for ungrounded loose or floating objects in the tank and remove them (i.e. loose gauge floats and sample cans).

f) Avoid pumping substantial amounts of air or other entrained gas into the tank through the liquid. In particular, the practice of clearing fill lines by air-blowing should be prohibited when the material is a flammable liquid or a combustible liquid heated to within 15 °F to 20 °F (8.5 °C to 11 °C) of its flash point.

g) To minimize charge generation, some operators limit the maximum fill rate after the initial fill rate is complete. A maximum fill rate between 23 ft/s and 33 ft/s (7 m/s and 10 m/s) is commonly used. Additional guidance can be found in industry recommended practices such as NFPA 77.

If the vapor space in a tank is at or above the lower flammable limit because of the previously stored product and the tank is to be filled with a low vapor pressure static accumulating liquid, the precautions outlined above should be followed. An alternative is to purge or ventilate the tank to a safe vapor concentration prior to filling (see Annex A.8.6).

The protective measures described above apply to floating-roof tanks only until the roof is floating. After the roof is floating, these precautions (except for item f) are unnecessary because the liquid surface is grounded by the floating roof and the absence of a significant vapor space. Care must be taken, however, to ensure that floating roofs are in metallic contact with the shell. Following the recommendations described in 5.4.2.2 for lightning protection will also provide static protection. Some types of floating covers, though nonconducting, are constructed with isolated metallic clips, which if not bonded, can become charge accumulators and spark promoters.

4.5.3 Grounding

Storage tanks on grade-level foundations are considered inherently grounded for dissipation of electrostatic charges, regardless of the type of foundation (i.e. concrete, sand, asphalt). For elevated tanks, the resistance to ground may reach 1 megohm (1 million ohms), but is unlikely to exceed this value. Therefore, the tank can still be considered adequately grounded for dissipation of electrostatic charges.

The addition of grounding rods and similar grounding systems will not reduce the hazard associated with electrostatic charges in the fluid. However, additional grounding may be required for electrical safety (NFPA 70) or lightning protection (see Section 5 and NFPA 780, 2014 Edition).

4.5.4 Spark Promoters

Care should be exercised to avoid spark promoters, such as unbonded conductive objects, within a storage tank. A tank gauging rod, a high-level sensor or other conductive device that projects downward into the vapor space of a tank can provide a place for a brush discharge to occur above the rising liquid. If these devices are conductive, they should be bonded securely to the bottom of the tank by a conductive cable or rod (to eliminate a spark gap) or placed in a gauging well that is bonded to the tank. Some high-level sensors currently on the market are not designed to accommodate a bonding cable or rod. In these situations, a bonding rod or cable could be installed immediately adjacent to the sensor or placed in a gauging well. Although chains have been historically used for bonding conductive projections, their use is not recommended because a conductive path cannot be guaranteed.

Periodic inspection should be conducted to ensure that bonding cables do not become detached. If the above devices are nonconductive, the above measures are not required.

Devices that are mounted to the interior sidewall of the tank (i.e. level switches, temperature probes), and which project a short distance into the tank but have no downward projection, may not pose an electrostatic hazard. These situations should be evaluated on an individual basis.

4.5.5 Blending Tanks and Mixers

Conventional low-speed propeller mixing has been in use for many years without evidence of problems from static generation. Tank jet mixing and high velocity propeller mixing can stir up water and debris and can generate an electrostatic charge during mixing and subsequent settling. If a flammable mixture exists at the surface, ignition may be possible. Jets should not be allowed to break the liquid surface. Some instances of static ignitions during high-velocity mixing under these conditions have been reported. Floating-roof tanks, which eliminate the vapor space, are especially desirable for blending service because they eliminate the flammable vapor space conditions that could otherwise exist. As an alternative to a floating-roof tank, gas blanketing may be employed (see A.8.6).

Besides the possibility of creating a flammable atmosphere, air-blown agitation is a prolific generator of static electricity and is not recommended. Steam agitation is also a prolific generator of static and is not recommended.

Hydrocarbon or inert gas agitation creates a static charge, but in small tanks it may be possible that the vapor space could be enriched or inerted as a result of the operation and this may be sufficient to prevent ignition. Mitigative actions could include beginning the process slowly to ensure the electrostatic charge does not build faster than the charge is dissipated, or purge the vapor space prior to mixing and observing waiting time prior to any gauging or sampling activities. Mist or froth generation may also be of concern in such designs.

4.5.6 Sampling and Gauging

4.5.6.1 General

Sampling and gauging operations (including temperature measurement) can introduce spark promoters into a storage tank, increasing the likelihood for a static discharge. During tank filling operations an electrostatic charge can accumulate on the product because of various charge mechanisms (see 4.5.2). Where possible, a conductive gauge well is recommended for all manual sampling and gauging. To be effective, the gauge well needs to be attached to the top and bottom of the tank so as to prevent the development of a large voltage on the surface of the product within the well.

4.5.6.2 Waiting Period

Where a flammable atmosphere can be expected in the vapor space of a tank, metallic or conductive objects such as gauge tapes, sample containers, and thermometers should not be lowered into or suspended in the compartment, either during or immediately after loading of product. Depending on the compartment size and the conductivity of the product being loaded, a sufficient waiting period should be followed to permit the product charge to dissipate.

A 30 minute waiting period is recommended before gauging or sampling large storage tanks, greater than 10,000 gal (37,850 L) if a gauge well is not being used. This recommendation is based on measurements taken in large tanks after loading, which show a slower decay of the field strength than normally expected for charge relaxation. This slower decay probably results from further charge generation because of the slow settling of small charged particles of water, dirt and other foreign debris and materials.

If a gauge well is not being used, and the tank or vessel is smaller, the recommended waiting period before gauging or sampling can be lower: 5 minutes for tanks between 5000 gal (18,925 L) and 10,000 gal (37,850 L); 1 minute for tanks less than 5000 gal (18,925 L). Longer waiting periods may be appropriate for ultra-low conductivity liquids, such as very clean solvents and chemical-grade hydrocarbons.

A waiting period theoretically is not necessary if a gauge well is used which “ensures” shielding of the fluid within the well from the bulk liquid electrostatic charge. However, many gauge wells and poles have holes or slots that could allow flow of static charges to the fluid within the well. Some companies choose to utilize the suggested waiting periods for all tanks.

4.5.6.3 Sampling and Gauging Devices

Sampling and gauging devices should be either completely conductive or completely nonconductive. Conductive sampling and gauging devices should not be used with a nonconductive lowering device (handle, cable, dry clean natural fiber rope, synthetic fiber rope, rod, etc.). Conductive sampling and gauging devices should be used only with a conductive lowering device, such as tape or cable.

Conductive sampling and gauging devices (including the sampling container and lowering device) should be properly bonded to the tank. 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.

Totally nonconductive hand gauging or sampling devices are those that do not contain any metallic components, such as weights, caps or labels; or those in which any metallic component, such as the weights, are encased in at least 0.4 in. (1 cm) thick nonconductive material resistant to impact and breakage. Theoretically, if a totally nonconductive hand gauging or sampling device is used, a waiting period is unnecessary. However, it should be noted that these devices might not retain the necessary high level of non-conductivity because of environmental factors (e.g. moisture or contamination). Therefore, the appropriate waiting period is also recommended when nonconductive devices are used.

Synthetic fiber (e.g. nylon and polypropylene) rope is not recommended. Tests have shown that when synthetic ropes rapidly slip through gloved hands for appreciable distances, such as into large tanks, an insulated person can become charged. Clean dry natural fiber rope can be nonconductive when used in low humidity conditions.

When used, natural fiber ropes should maintain contact with the tank hatch because they might be conductive if not kept clean and dry (free of moisture).

Automatic gauging devices can be used safely in tanks. However, gauge floats should be electrically bonded to the tank shell through use of a conductive lead-in tape or a conductive guide wire. Freely-floating unbonded floats can act as spark promoters and should be avoided.

4.5.7 Purging and Cleaning Tanks and Vessels

4.5.7.1 General

A complete discussion of the proper methods and procedures required for the purging and cleaning of tanks can be found in API 2015 and API 2016. NFPA 69 provides additional guidance. The purging and cleaning processes involve a number of different safety issues that are beyond the scope of this document. This section provides particular guidance regarding electrostatic hazards only.

4.5.7.2 Purging

Purging involves removing a fuel vapor from an enclosed space and completely replacing it with air or inert gas. Electrostatic hazards involved in purging depend on the media and the equipment used.

Steam cleaning of tanks, steam blanketing, and similar operations should be avoided when the tank or vessel contains a flammable atmosphere, or may develop a flammable atmosphere during the operation, since steam can introduce a charge before inerting is complete. In addition, condensation of the steam will draw in air, possibly creating an explosive atmosphere in an unsealed container. In a nonconductive vessel, or a vessel with a nonconductive lining (see 4.6.6), charged condensate from steam can accumulate under some circumstances, a condition that can create a charged conductive "object" within the container. Steam jets used for purging can generate static charges on the nozzle, insulated objects on which the steam impinges, and through the formation of a charged mist. If steam is used to purge a tank or other equipment, all conductive objects (including the steam discharge pipe or nozzle), should be bonded to the tank or equipment.

A CO_2 jet used for purging can be an effective static generator if solid particles (CO_2 "snow") are created during the discharge. The same precautions against static buildup described for steam jets should be followed. If CO_2 is used for inerting, it should be released in a way that does not allow solid carbon dioxide particles to form.

CO_2 fire extinguishers normally produce solid CO_2 particles when discharged and thus are prolific static generators. Explosions have resulted from discharging CO_2 extinguishers into tanks that contain a flammable vapor-air mixture. CO_2 extinguishers should not be used to inert flammable atmospheres. For small tanks or vessels where time permits, the use of dry ice (solid CO_2) has provided slow inerting of confined spaces.

Other purging media such as clean air and nitrogen do not typically present a static hazard when discharged at low velocity.

4.5.7.3 Cleaning

When steam is used as a cleaning medium, electrostatic hazards should be considered. See 4.5.7.2 for specific guidance on steam.

When water or water based solutions are used for cleaning with jets, sprays or fog nozzles, the potential exists for electrostatic charge generation as a result of mist formation and water settling through hydrocarbon product. Water washing using sprays should only be conducted in an inerted or non-flammable atmosphere. Although specifically written for marine cargo tanks, the OCIMF *International Safety Guide for Oil Tankers and Terminals* presents a comprehensive discussion of tank cleaning and can be used for further guidance.

Flammable solvents and combustible materials, such as diesel fuel, are occasionally used for tank cleaning. Proper safeguards should be employed because of the potential for flammable atmosphere created by the cleaning process. Mists created by the cleaning solvent can create a flammable atmosphere (see 4.6.11). Also, heat, agitation of sludge, and removal of scale can release flammable vapors.

Where a flammable 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. Entry of workers into inert atmospheres requires specific equipment and training (API Std 2217A) and should be avoided unless no other options are feasible.

Where the vessel is not inerted consider the following precautions when using solvent as a cleaning agent.

a) Only use conductive solvent (greater than 50 pS/m). This can be done by using high-conductivity solvent, by additive to increase conductivity or by using sludge from the tank to “dirty-up” the solvent. Conductivity may need to be checked periodically based on the cleaning process.

b) Only use high flash point material (flash point 15 °F to 20 °F (8.5 °C to 11 °C) greater than the operating temperature during cleaning). The flash point should be confirmed on a daily basis.

c) The application system should be conductive and bonded to the tank. Conductivity tests of all bonded equipment should be conducted prior to each day’s use and shall not exceed the requirements set out in 3.1.2.

d) Use a nozzle and delivery system that does not generate a fine mist or aerosol. Do not introduce ungrounded conductive objects into the tank during the cleaning process or for a sufficient time period after the cleaning process (the waiting period may be several hours, see 4.6.11).

e) Monitor the flammability of the vapor space.

Cleaning operations involving manual entry may also have the potential for generating electrostatic charges. It is critical that the tank or vessel is gas-free and the flammable material is reduced to a safe level before entry. Additionally, provisions should be made for continuous monitoring of the vapor space for hydrocarbons.

4.5.8 Floating-roof Tanks

Tanks with conductive floating roofs in contact with the product are inherently safe from static charge accumulation provided that the roof is bonded to the shell. If the roof is landed, charge accumulation in the surface of the liquid may occur and appropriate precautions need to be taken.

4.5.8.1 Open and Internal Floating Floating-roof Tanks

Internal floating-roof tanks require some form of bonding; either by the use of shunts or a metal cable between the floating roof or cover and the tank roof or shell (refer to API 545 and API 650, 12th Edition, Annex H). This will sufficiently remove any electrostatic charges on the floating roof or cover.

Accumulation of weathered oil on the inner tank shell, corrosion, and “out of round” tank shells can reduce the connection of shunts to the tank shell, thus reducing conductivity. Routine inspection and maintenance is necessary to ensure that shunts are in contact with the shell.

4.5.9 Nonconductive Tanks and Linings

4.5.9.1 Aboveground Tanks

It is not recommended to store flammable liquids in nonconductive (e.g. plastic, fiberglass) aboveground tanks.

A plastic tank may be equipped with a metallic manhole and fluid openings. Tests have shown that conductive (metal) fittings accumulated potentials up to 11 kilovolts while dispensing product into an insulated tank. Visible sparks were recorded when a grounded conductor was brought near the tank. This was true of metallic objects not in contact with the contents but simply in contact with the outside of the shell. The charge resulted from induction through the plastic itself.

When nonconductive tanks are used for hydrocarbon storage or storage of materials that may be contaminated with flammable products, significant electrostatic concerns are introduced. The major concerns are as follows:

a) the electrostatic field is not confined to the interior of the compartment (such that discharges could be induced externally to the tank or in an adjacent compartment); and

b) there is no efficient means for charge dissipation from the fluid (such that the probability of internal discharge is increased).

Tests indicate that to ensure the safe dissipation of charge and prevent discharges, the following features should be incorporated in the tank if the atmosphere could be flammable.

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

b) When used to store low-conductivity products (less than 50 pS/m), the following additional features should be provided.

   1) An enclosing grounded conductive shield to prevent external discharges. This shield may be in the form of a wire mesh buried in the tank wall, as long as it is grounded, and the shield should include all external surfaces.

   2) The tank should have a metal plate with a surface area no less than 30 $in.^2$/100 gal (194 cm^2/379 L) located at the tank bottom, and bonded to an external ground. This plate provides an electrical path between the liquid contents and ground through which the charge can dissipate.

c) When used to store high-conductivity products, either provide a grounded fill line extending to the bottom of the tank or an internal grounding cable or rod extending from the top to the bottom of the tank and connected to an external ground. If a grounded fill line enters at the bottom and does not introduce a spark promoter, this is sufficient.

4.5.9.2 Buried Tanks (Underground Storage Tanks)

The majority of this tank type is used for the dedicated storage of motor fuels. In this service, the atmosphere within the tank is either too rich or too lean to support combustion. Therefore, special static discharge precautions are not normally employed. In other services, the same precautions that are applied to above ground storage tanks are recommended (see 4.5.9.1).

4.5.9.3 Nonconductive Linings

See 4.6.6 regarding tanks with nonconductive internal coatings and linings.

4.6 Miscellaneous Electrostatic Hazards

4.6.1 Aircraft Fueling

For a comprehensive discussion of aircraft fuel servicing see NFPA 407 and API/IE 1540. Only a brief outline of the electrostatic precautions required is included here.

Prior to making any fueling connection to the aircraft, the fueling equipment should be bonded to the aircraft by use of a bonding cable. NFPA 407 specifies a maximum resistance of 25 ohms for the connection. Where a hydrant servicer or cart system is used, the hydrant coupler should be connected to the hydrant system prior to bonding the fuel equipment to the aircraft. The bond should be maintained until fueling is completed and bonding and fueling connections should be disconnected in the reverse order of connection.

NOTE The bonding procedures included here are consistent with NFPA 407. EI 1540, *Design, Construction, Operation and Maintenance of Aviation Fueling Facilities,* 2014 Edition, provides flexibility for use of alternate bonding sequences. Section 9.2.4.2(d) states "The connection for hydrant fueling should follow local or national standards." (Annex B-2 cites the following four standards regarding bonding: API 2003; ATA Specification 103; *JIG Guidelines for fueling*; NFPA 407.) Where local or national standards do not exist, the recommended practice should be followed. In some regions the bonding sequence is reversed with the equipment first connected to the aircraft. Facilities and regions should maintain consistent successful bonding practices. Bonding research is ongoing.

When over wing fueling, in addition to the bonding connection mentioned above, the nozzle should be bonded to the aircraft by means of a nozzle bond cable with a clip or plug connected to the tank filler port. The bond connection should be made before the filler cap is removed and should be kept in place until the fueling is completed. If a funnel is used in aircraft fueling, it should be kept in contact with the filler neck, the fueling nozzle, and the supply container. Only metal funnels should be used.

Conductive hose, API Type C (10^3 ohms to 10^6 ohms/m) per API/EI 1529 or equivalent, should be used for fueling. An independent bond is still required when using a conductive hose.

While bonding is necessary, grounding of the aircraft and fueling equipment is not recommended for protection from static during fueling. The static wire might not be able to conduct the current in the event of an electrical fault in the ground support equipment connected to the aircraft and could constitute an ignition source if the wire fuses. If ground support equipment is connected to the aircraft or if other operations are being conducted that necessitate electrical earthing, separate connections should be made for this purpose. Since static electrical grounding points may have high resistance they are unsuitable for grounding. Local airport regulations, however, may require use of a grounding system. The same precautions specified above should be used for de-fueling aircraft.

The loading of the aircraft fuel servicing tank vehicles shall be in accordance with 4.2.

4.6.2 Drive Belts and Pulleys

Belts made of rubber, leather, or other insulating materials, running at moderate or high speeds, can generate significant quantities of static electricity. For more specific guidance on belt conductivity, see ISO 1813 and ISO 9563.

The static generation occurs when the belt separates from the pulley, creating a charge on the pulley (regardless of whether it is conducting or non-conducting) and on the belt. If the pulley is made of conducting material, the charge will normally dissipate through the shaft and bearing to ground and will not present an ignition hazard. If the machinery frame is insulated or the bearings are composed of insulating materials, such as nylon, then bonding and grounding may be required.

Using a conductive belt can eliminate accumulation of static charges on the belt. The non-static generating characteristics of conductive belts apply to new clean belts. The user must assume responsibility for establishing an effective preventive maintenance program to ensure continued safe operation.

Another means of preventing the accumulation of static charges on the belt is by making the belt conductive with belt dressings. These dressings must be renewed frequently to be reliable or effective. Hence, relying exclusively on a belt dressing is not recommended because greater maintenance effort is required.

Additionally, a static conductive brush or similar device can be used in some situations to bleed off static buildup on the belt (by inducing a non-incendive corona discharge). Relying exclusively on a conductive brush or similar device is not recommended because greater maintenance effort is required to ensure its continued proper operation.

4.6.3 Filters and Relaxation Chambers

4.6.3.1 General

Charge generation greatly increases (see Figure 8) if a filter is placed in a piping system. A filter can produce from 10 to 200 times more charge than is produced in the same system without filtration. In some cases, wire screens can also enhance charge generation. There is no danger from this excessive charge as long as the liquid is contained in the pipe; the absence of air will not allow any flammable mixture to ignite. Furthermore, the high charge developed by the filter tends to decrease as the liquid continues down the pipe (see Figure 9).

If, after filtration, the liquid is discharged from the pipe into a container where the possibility of a flammable mixture exists (as with intermediate vapor pressure products, switch loading, or contaminated low vapor pressure products), specific precautions may need to be taken.

When the pore or screen size of the filter is larger than 300 microns (less than 50 mesh/in.), it is unlikely that hazardous levels of electrostatic charge will be generated in the filter/screen. Therefore, no specific provision for downstream relaxation is necessary.

As the filter pore size decreases (mesh/in. increases), charge generation also increases and may approach a hazardous level. When the pore or screen size is less than 150 microns (more than 100 mesh/in.) a hazardous charge level is likely to be generated, particularly if the filter or screen is partially plugged. In this situations, a residence time of at least 30 seconds should be provided between the filter or screen and the point of discharge. With pore sizes between 300 microns (50 mesh) and 150 microns (100 mesh), safe operations may be possible based on the results of a risk assessment of the facility, which considers such factors as the materials being handled and the operating procedures in place. Regardless of the pore size, both filters and wire screens should be cleaned or replaced if the pressure drop becomes excessive, because charge generation increases when the filter and screen becomes partially obstructed.

In practice, providing piping downstream of the filter that is long or wide enough to retain the liquid for 30 seconds prior to discharge (see Figure 9) attains residence time. The charge on the liquid is then relaxed to a value that is considered safe. The same result can be obtained by keeping the liquid in a relaxation chamber for 30 seconds or by reducing the flow rate. A relaxation chamber should operate full of liquid to avoid the possibility of sparks occurring in a flammable vapor space.

A provision of at least 30 seconds residence time (and preferably 100 seconds) after filtering is recommended as a design criterion for all new equipment, regardless of the product or service. Applied to filling of tankers, tanks, and containers, as well as to loading racks, this design consideration will provide protection if the equipment is converted to another service or if the product is inadvertently contaminated. It will also provide protection where switch loading may take place. From a technical standpoint, however, the requirement for residence time can be disregarded for products whose conductivity is greater than 50 pS/m (see A.5) at the operating temperature involved. This conductivity level can exist inherently or can be achieved through the use of a static dissipating additive (see A.8.5).

4.6.3.2 Ultra Low Conductivity Products

For fluids exhibiting both very low conductivity (less than 2 pS/m) and high viscosity (greater than 30 centistokes) at the lowest intended operating temperature, longer residence times downstream of small pore size filters and screens

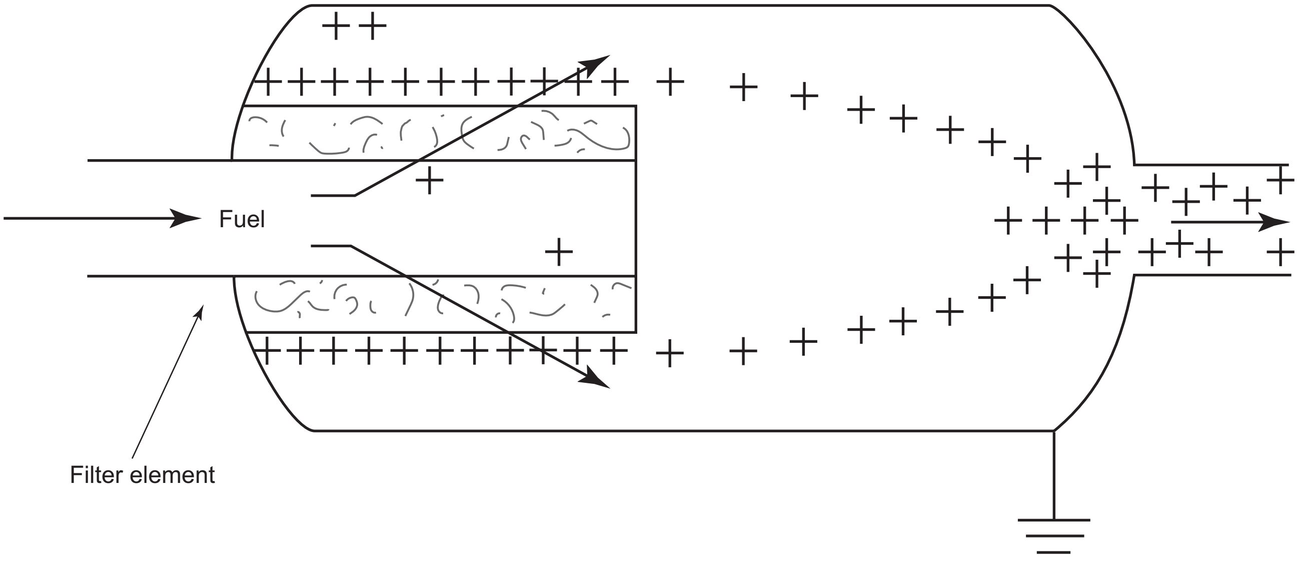


Figure 8—Charge Separation in a Filter

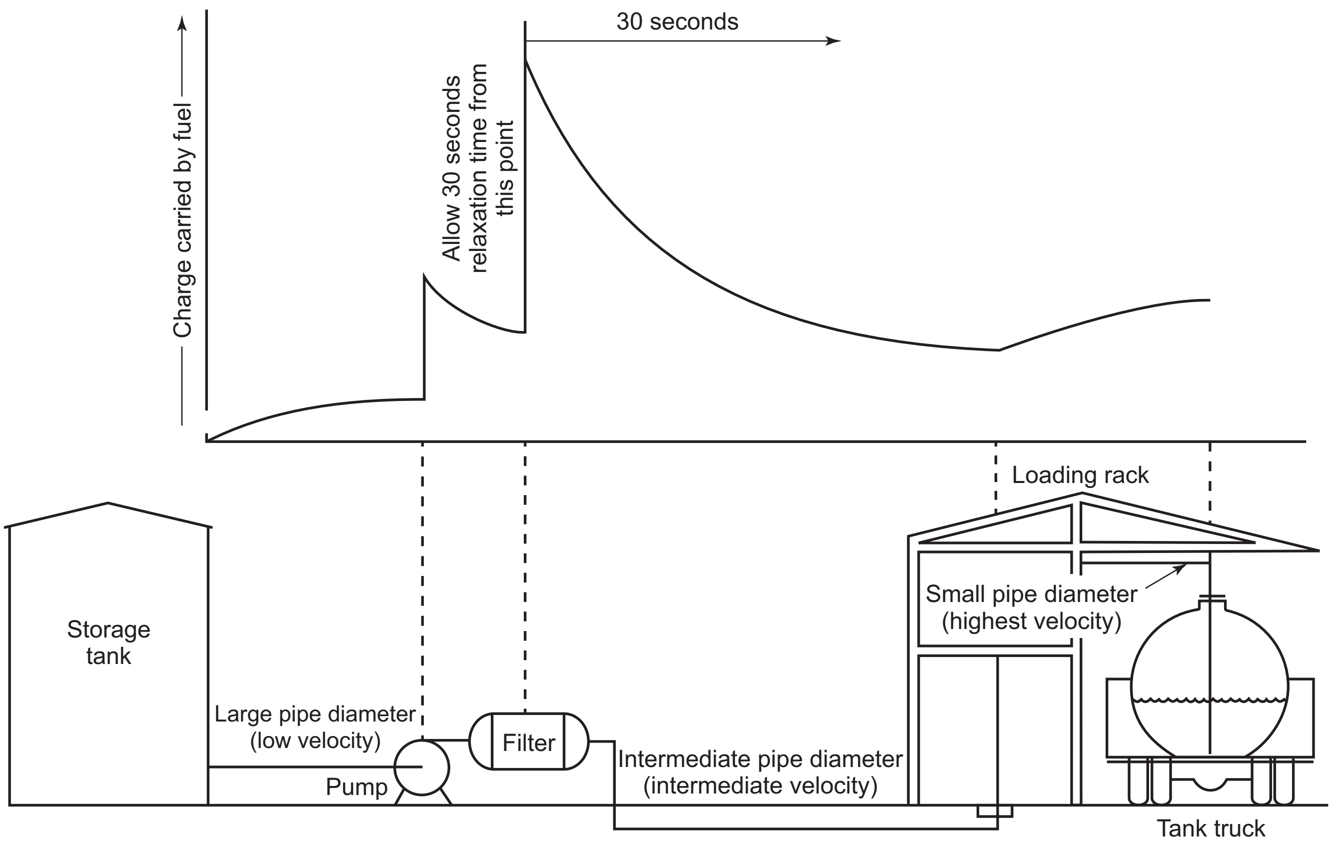


Figure 9—Electrostatic Charge Generation During Tank Truck Loading Update Using Clear Copy

may be appropriate. In these cases, a residence time of up to three times the relaxation time constant of the fluid should be considered after a suitable review of the risk and potential charge generation mechanisms. The required residence time typically will not exceed 100 seconds except where other guidelines in this document (such as switch loading precautions or the limitation on initial fill-in rate) are not being followed. Where conductivity cannot be verified a 100 second minimum residence time should be used. Also, see 4.2.5.6.

4.6.3.3 Filter-separators

An electrostatic discharge can char or damage new filter elements inside a jet fuel filter-separator, even if the fuel has been treated with a conductivity additive, regardless of the aviation turbine fuel handled (JP-4, JP-5, JP-8, Jet A, Jet A-1). When filter elements are replaced, the filter-separator should be gravity filled when possible, or the flow velocity should be reduced to 1 m/s (3 ft/s) until the filter-separator is full of liquid.

4.6.4 Portable Metal Containers

Portable metal containers include portable metal tanks (tote tanks) up to 660 U.S. gal (2574 L) capacity, metal drums, and metal cans of various sizes. For nonconductive portable containers see 4.6.5.2.

Portable metal containers should be bonded to the filling system, either by a bond wire or continuous contact between the container and metallic-filling spout. Plastic handles on the bail of an open metal buckets can insulate the bucket preventing bonding by continuous contact if bucket is suspended from a metal spout. In these cases a bond wire would be required to dissipate accumulated charge. Portable metal containers filled on metal conveyors or on a conductive surface that is inherently bonded to the fill system do not require a separate bond. When filling portable tanks and drums with flammable liquids, it is advisable to avoid splash filling. A metal fill pipe that extends to near the bottom of the tank or drum should be used. Adequate residence time should be provided downstream of any Micropore filters (see 4.6.3).

Metallic cans may be safely filled through metallic spouts provided they are maintained in contact with the can throughout the filling operation (see Figure 10). In some cases, it is difficult to guarantee that the required level of contact will be maintained throughout the entire filling operation. In these cases, bonding wires should be provided between the fill pipe and the can. If a conductive funnel is used in the filling operation, the funnel must also be bonded to both the can being filled and the fill piping. If a nonconductive filling funnel is used, only the fill pipe needs to be bonded to the can.

The use of open metal sampling containers (buckets) for the collection of samples of flammable materials is not advisable. The larger top surface exposed to the atmosphere makes it more likely that an ignitable vapor-air mixture will exist in and around the container. However, when open metal sampling containers are used; they must be bonded to the fill pipe. Closed metal sampling containers that are directly connected to the fill system are inherently bonded and do not require additional bonding.

4.6.5 Nonconductive Equipment and Materials

4.6.5.1 General

In most of the preceding discussions, it has been assumed that the equipment in which petroleum is handled is made of electrically conductive material. The precautions mentioned have mainly involved steps to prevent a potential difference from building up between two such bodies or between one such body and the earth or an extensive oil surface.

A different approach is necessary when equipment is made of nonconductive material. The bonding previously suggested as a necessary precaution for electrically conductive materials now becomes impractical. In general, the basic precautions to be taken are: bond and ground all isolated conductive components; provide a path to ground for all fluids.

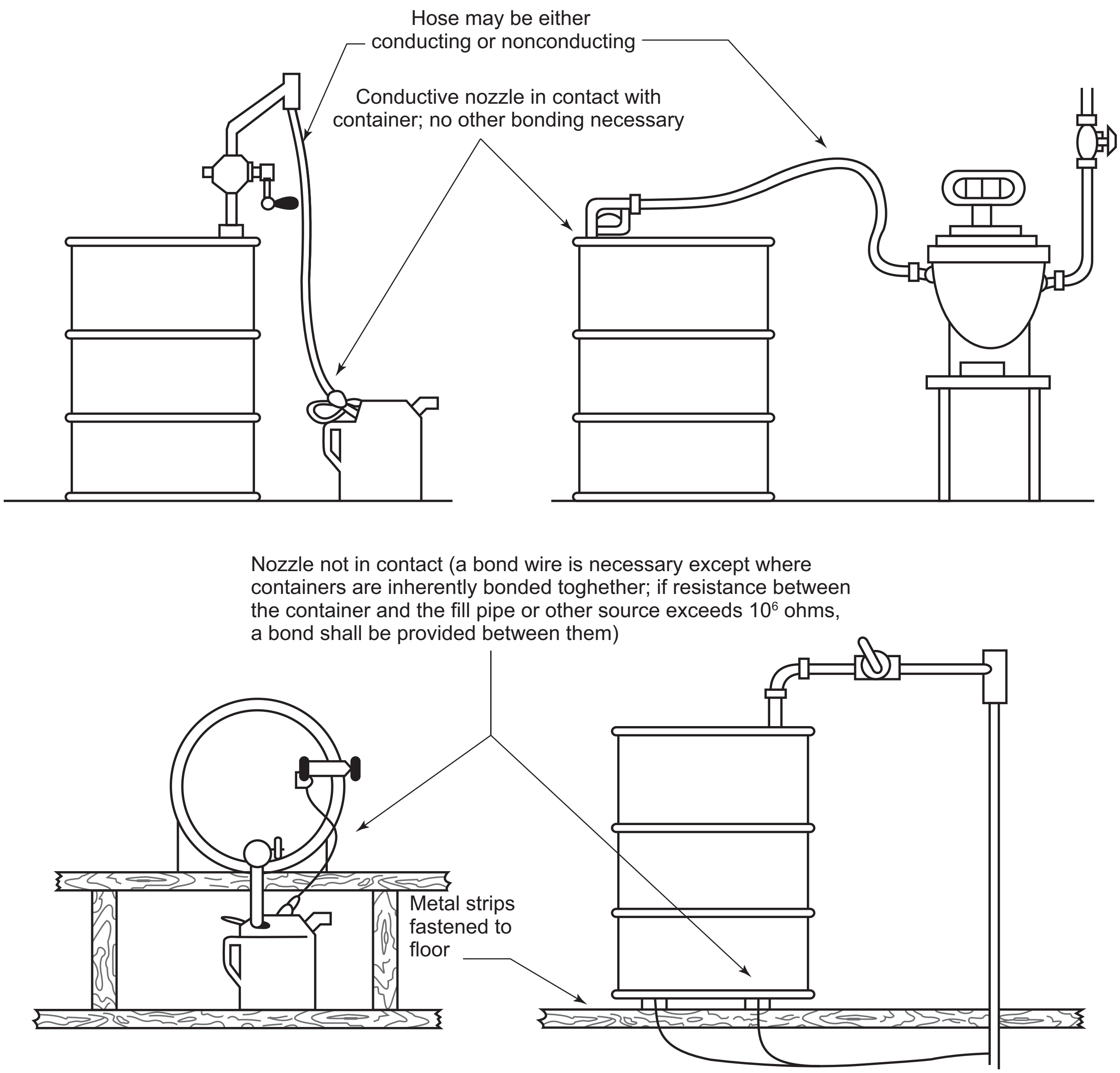


Figure 10—Bonding During Container Filling

4.6.5.2 Nonconductive Portable Containers

A nonconductive portable container has a capacity of 660 gallons (2574 L) or less and is constructed of an electrically nonconductive material. The more common nonconductive containers include glass and plastic bottles, plastic buckets, plastic cans and drums, and plastic bulk shipping (tote) tanks. Plastic-lined metal drums and bulk shipping tanks should also be considered as nonconductive containers (see 4.6.6).

The filling of nonconductive portable containers with combustible liquids at temperatures at least 15 °F (8 °C) below their flash point, presents no significant static ignition hazard. Filling of a nonconductive container with a combustible liquid above or within 15 °F (8 °C) of its flash point should be handled as a flammable liquid. In addition, if refilling a bulk-shipping tank that may contain flammable vapors from a previous product, ignition could occur similar to the "switch loading" of a tank truck, and should not be allowed. Additionally, the routine handling of nonconductive containers filled with any type of liquid can generate a static charge on the outside surface of the container. These containers should not be handled in an area where there may be ambient ignitable vapors.

The precautions for filling nonconductive containers with flammable liquids depend on the size of the container, the container design, and the conductivity of the liquid.

Nonconductive containers of any size can be safely filled with flammable liquids with conductivity greater than 50 pS/m provided there is a conductive path from the liquid in the container back to the filling source. Generally, if a container is nonconductive, bonding or grounding (the nonconductive surface) serves no useful purpose; however, any metal parts on the nonconductive container should be bonded to the fill pipe. When a nonconductive container is filled with a flammable liquid, the conductive fill pipe or a conductive metal rod (or wire) that is bonded to the fill system should always be in contact with the liquid while filling. The fill pipe or metal rod should be inserted to the bottom of the container before filling and remain until the filling is completed.

For filling larger portable containers, such as plastic 55 gal (208 L) drums or plastic 660 gal (2574 L) "tote-tanks," a conductive metal downspout that is bonded to the dispensing system should be used. The downspout should extend within 1 in. to 2 in. (2.5 cm to 5 cm) of the bottom of the drum or tank. The downspout should be designed to minimize splashing and spray. Filling velocities should be less than 3 ft (1 m) per second. When filling product at or above 50 pS/m, the downspout should remain in contact with the liquid for 30 sec after filling is complete to allow for charge dissipation.

When filling nonconductive portable containers with flammable liquids below 50 pS/m, additional precautions should be taken. The maximum distance possible should be used between Micropore filters or other charge generating elements and filling points. A residence time of at least 30 seconds for most fluids should be employed. Experimental data indicates that charge dissipation through a grounded immersed fill pipe is significantly more effective if there are no external ground surfaces within 12 in. (30.5 cm) of the container, vertically or horizontally. A larger diameter fill pipe is more effective in removing charge. When filling materials below 50 pS/m, the grounded fill pipe should be left in the drum for 5 minutes after filling has stopped.

When using a nonconductive container with a conductive spigot to fill a conductive container, bond the conductive spigot to the conductive receiving container to prevent an electrical charge from accumulating on the isolated conductor (spigot).

4.6.5.3 Nonconductive Surfaces

Sheet plastic is occasionally used around petroleum operations. If sufficiently charged, such a surface can yield a visible spark when approached by a conducting object, and under carefully controlled laboratory conditions, such sparks have produced ignition. The use of sheet plastic should therefore be avoided where flammable vapor might be present.

4.6.6 Internal Coatings and Linings

A thin coat or layer of paint, plastic or metal oxide (rust) on the inside of piping, vessels, or equipment does not constitute an electrostatic hazard because their resistivity is of the same magnitude as that of oil or because of small bare areas (holidays) in the coating. At owner's discretion the presence of internal coatings or linings in grounded metal tanks can generally be disregarded, provided that one of the following criteria applies:

a) The coating or lining has a volume resistivity equal to or lower than 10^9 ohm- m,

b) Thickness of a painted coating does not exceed 2 mils (50 µm).

c) The liquid is conductive and is always in contact with ground, for example, a grounded dip tube or grounded metal valve.

Storage tanks, tank truck or tank car compartments, piping and other metallic equipment with nonconductive linings should be treated as nonconductive equipment (see 4.5.9). Regardless of the lining thickness or resistivity, metal containers and tanks should be bonded to the filling system and adequately grounded.

Lined piping and fittings may contribute to charge generation. Flow time through lined piping and delivery system components should not be included in determining the residence time.

4.6.7 Vacuum Truck Operations

Explosions and fires could occur during vacuum truck operations because of the following risk factors:

a) ignition of a flammable atmosphere in the container being vacuumed;

b) ignition of a flammable atmosphere generated in the areas around the vacuum truck or equipment being vacuumed;

c) ignition of a flammable atmosphere inside the vacuum truck.

See the OCIMF *International Safety Guide for Oil Tankers and Terminals* for vacuum operations in marine applications and for land-based vacuum trucks see API 2219, *Safe Operation of Vacuum Trucks in Petroleum Service*.

The following precautions should be taken if there is a risk of a flammable atmosphere during vacuum truck operations.

a) Use conductive vacuum hose and fittings per API 2219. Hose should be regularly checked for electrical continuity. Hoses constructed of conductive material or thick-walled hoses with embedded conductive wire should be used. Alternatively, nonconductive hose can be used provided that all conductive fittings are bonded. However, special considerations and controls are required to ensure bonding integrity is maintained in this difficult environment and that there are no ungrounded conductive objects connected to the hose.

b) Thin wall, plastic hose with a spiral wound conductive metal spring backbone should not be used because of the possibility of electrical breakdown through the thin plastic next to the metal spiral

c) The complete system needs to be bonded so that there is a continuous conductive path from the truck through the hose and nozzle to the tank. Bonds should not be broken until all transfer equipment (hose) has been withdrawn from the container opening.

d) Avoid the use of unbonded conductive objects such as metal funnels.

e) Ground the vacuum truck prior to each operation, except where closed connections and conductive hose serve as a ground. (See item a above.)

f) Portable, nonconductive containers should not be used as an intermediate collection vessel during vacuum truck operations because of charge accumulation on the container. Only conductive containers should be used and bonded to the hose nozzle and the container being drained.

g) Bonding of a conductive hose nozzle which is not in contact with the conductive container can be accomplished by the use of a conductive hose and a bonding wire from the container directly to the vacuum truck. See item (a) this section

Hoses should be marked as conductive or nonconductive to help avoid misapplication.

4.6.8 Abrasive Blasting and Spray Painting

During abrasive blasting, static is generated by grit flowing through the blasting machine and hose. Bonding should be provided between the blast nozzle and the work surface and the work surface should be grounded. Sparks have been observed jumping from the rubber hose to grounded objects during grit blasting. Therefore, extreme care should be exercised so that the hose does not pass through a flammable atmosphere. Special hoses with built-in metallic shielding, which prevents sparking from the hose to ground, are available from vendors on special order. Carbon conductive hose is also available. To be effective, this shielding must be more than just an internal bond wire embedded within the hose. It must be bonded to the nozzle and the machine. Within the stream pattern, no flammable concentration is likely to exist because of the sweeping action of the air stream (for additional information, see API 2027).

Entry into inert atmospheres should be discouraged when alternate procedures are available (see API 2217A). Interior spray painting, coating or similar activities that produce a mist inside a vessel or storage tank and where proper inert entry protective personnel precautions are not practical, the following precautions should be employed in normal atmospheric air work environments:

a) provide adequate ventilation based on the spraying rate to maintain the vessel atmosphere below 10 % of the LFL;

b) maintain continuous monitoring of LFL;

c) select a high flash point material;

d) bond all facilities including the spray equipment;

e) use conductive paint hoses as specified by the equipment manufacturer;

f) conduct an OSHA 1910.132(d) hazard analysis to determine worker protection (PPE) needs;

g) ensure conformance to other OSHA requirements as appropriate (such as *Permit Required Confined Space Entry 1910.146 and Hazard Communication* 1910.1200).

Additional precautions not related to electrostatics are also necessary (such as the use of explosion-proof electrical equipment).

4.6.9 Service Stations

4.6.9.1 Tank-truck Deliveries

No bonding is required when delivering via the bottom connection or closed delivery system from a tank truck to the service station tanks. The connection from the delivery hose to the tank fill connection should be liquid tight. The delivery hose may be conductive or nonconductive. Vapor recovery and vapor balance systems on these tanks generally do not increase the potential for static ignition. However, these systems should be designed and arranged so as to preclude the possibility of introducing flammable vapors into diesel and kerosene tanks.

4.6.9.2 Motor Vehicle Fueling

Motor vehicles can acquire an electrostatic charge while traveling. Tests have shown that in almost all cases, this charge dissipates to ground very quickly (seconds or less). The resistance offered by the tires through concrete surface is low enough that charge dissipation is not inhibited to a significant extent within this time frame. Thus, the voltage on a vehicle upon arriving at a service station will usually dissipate prior to the initiation of filling.

Under very dry conditions, an asphalt surface may offer sufficient resistance that the charge will not dissipate in a timely manner. A small number of incidents have occurred in European locations where a special polymer-coated paved surface, having unusually high resistance, was used at service stations to prevent soil contamination from gasoline spills. Therefore, paved surfaces that result in a resistance greater than one megohm should not be used. This consideration should be integrated into hazard reviews associated with new facility construction or existing facility revamp. It is a consideration for inclusion in incident investigations.

Another potential source of static charge occurs when a person slides across the seat upon exiting a vehicle. On most surfaces, including concrete, this charge dissipates within a few steps. On very low conductive surfaces or with low conductive footwear the static charge may remain for a longer period; but, it will usually dissipate instantly when the customer touches a metal surface. The basic recommendation is "stay outside the vehicle while refueling."

The dispensing of gasoline from service station tanks to motor vehicle fuel tanks does not require bonding or grounding of the motor vehicle, provided the approved dispensing equipment is used. The dispensing nozzle should be in metal contact with the metal fill opening of the fuel tank before filling begins and should maintain contact until filling is complete.

A few rare incidents of ignition have been attributed to situations where the metal fill opening was electrically isolated from the body of the vehicle and from the gas tank. This is rare with automobiles, but could occur with some plastic bodied recreational vehicles and equipment. Recreational vehicles that are transported on trailers offer an additional opportunity for the creation of ungrounded components.

4.6.9.3 Portable Container Filling

From a static ignition concern, as well as other safety considerations, small portable containers should never be filled while in or on a vehicle. Small portable containers, up to 12 gal (45 L) capacity, made of metal or approved plastic construction are allowed for the storage and transportation of liquid fuels by most local authorities. When filling, these containers must be removed from the vehicle and placed on the pavement. For metal containers, the dispensing nozzle should remain in contact with the container during filling.

Grounded, large metal containers, drums and portable tanks may be filled while resting on the open bed of a truck or vehicle. To ensure electrical continuity to ground, these containers should be bonded directly to the vehicle chassis. If the truck bed has a nonconductive liner (i.e. plastic, rubber, etc.) a bonding wire is required. Under all circumstances, the dispensing nozzle should be in metal contact with the drum or tank before filling begins and should maintain contact until filling is complete. NFPA 30A should be consulted for further information on this subject.

4.6.10 Human Body and Clothing

The relative absence of reports within the petroleum handling industry of static ignition of petroleum vapors as a result of personnel electrification indicates that the hazard has not been historically significant. The reason for the lack of incidents is that most operations occur outdoors or in semi-enclosed locations where the work environment is inherently conductive as a result of contamination or moisture and where the exposure of personnel to flammable atmospheres is limited.

Ungrounded personnel that have acquired an electrostatic charge can present a serious hazard in potentially flammable atmospheres. Body electrification (charge generation and accumulation) is caused by a variety of activities, but physical separation of dissimilar materials is always involved in the generation of high body voltage.

Under favorable conditions, many fabrics can generate static electricity. Static discharges directly from clothing are highly unlikely to ignite ordinary hydrocarbon gases in the air. However, clothing can be a significant contributor to body charging as a result of its removal or movement relative to other clothing (e.g. wearing very loose coveralls). This possibility should be recognized and prudence exercised on any occasion when flammable vapors/gases are present. As a minimum precaution, clothing must not be removed in a potentially flammable atmosphere, loose clothing should be avoided, and hydrocarbon-saturated clothing should not be removed until personnel involved are adequately grounded.

All types of shoes, unless specifically designed not to, generate static charges when the wearer walks on nonconductive surfaces during periods of low humidity. For activities that take place under low humidity conditions, particularly indoors, antistatic floor mats can reduce personnel charging.

The hazard from personnel electrification is greatest in locations where a flammable atmosphere exists as a result of the operation being carried out. The primary means of risk reduction and prevention is to remove the personnel from such locations. Where the presence of personnel is needed, engineering controls (such as forced ventilation or containment of vapors) should be used to remove the hazard associated with flammable atmospheres.

If the presence of personnel is unavoidable and engineering controls are not sufficient to reduce the flammability hazard to an acceptable level (typically less than 10 % LFL for flammable vapors) then charging of personnel should be reduced using facilities designed to provide personnel with a means of reducing charge generation and safely discharging any accumulated electrostatic charge. Prevention of personnel charging is achieved by maintaining body grounding through the use of antistatic footwear, antistatic flooring, and providing locations or means to ensure personnel can remove any charge from their body prior to entering the hazardous area. These control measures are cited to illustrate that where a substantial risk from personnel electrification exists, the use of antistatic clothing alone is not sufficient.

The need for control of personnel charging usually arises most often in situations where workers are exposed to highly ignitable materials indoors, such as in hospital operating suites (with mixtures of oxygen and anesthetic gas) and in the manufacture of munitions. It can also arise in certain petroleum or petrochemical industry operations such as barrel filling of flammable liquids and in plastics handling operations.

4.6.11 Mists

Clean gases cannot carry a significant concentration of electrostatic charge. However, when the gas contains suspended solid particles or liquid droplets, (i.e. an aerosol or mist), a hazardous electrostatic charge concentration may develop. An electrostatic charge in an aerosol or mist can be generated during the atomization process as a result of flow through piping and equipment or as a result of contact with other charged objects. Because the suspended solids or droplets are not in electrical continuity with each other, the electrostatic charging mechanism does not depend on the conducting properties of the solid or liquid involved and charged aerosols/mists are possible with conductive as well as nonconductive materials. In addition, because the charge relaxation process requires settling of the mist, the required waiting period may be as long as five hours.

The hazard associated with aerosols and mists are threefold.

1) The possibility exists of generating a charge concentration (such as during tank cleaning with liquid jets) high enough that an incendive brush discharge can be generated between the charged aerosol or mist and grounded conductors present. API 2015 and API 2016 provide more specific guidance for work associated with tank cleaning.

2) The charged aerosol/mist can contribute a significant charge to the liquid, foam generated on a liquid surface, and isolated conductors that may be present within the enclosure or compartment.

3) The aerosol or mist itself may produce a flammable mixture in situations where the atmosphere would not normally be in the flammable range.

The basic precaution is the avoidance of the generation of aerosol/mist, such as by using submerged inlets and low initial filling rates. In situations where an aerosol or mist formation cannot be avoided or is intentional (as is the case with tank washing using either water or hydrocarbon liquids and a variety of spraying operations), it is recommended that the operation be carried out under an inert atmosphere. In addition, insulated conductors should be avoided/ removed and all facilities (such as spraying nozzles) should be bonded and grounded.

4.6.12 Plumbers Plugs

A plumber's plug is a mechanical device used to seal the end of a pipe that has not been decontaminated sufficiently to allow welding. Bond wires should be used to reduce the possibility of static discharge and ignition. The most common form of plumbers plug consists of two metal discs with a solid rubber disc between them. As the discs are pulled together (tightened) the rubber expands to make a tight vapor seal. By installing a plumber's plug and cleaning the pipe from the plug to the open end of the pipe a permit to weld can generally be authorized. Plumbers plugs must be vented and bonded as they are not designed to hold pressure above atmospheric and the rubber is nonconductive.

To avoid potential ignition the following precautions are normally followed to separate potential fuel and ignition sources.

a) The pipe is cleaned to the depth that the plug will be inserted to remove residual hydrocarbons and assure that a good seal can be achieved.

b) The plumbers plug shall be inspected to assure it is in good condition and properly sized.

c) The plug is inserted to a depth that will not be affected by the heat of the weld and tightened until a seal is achieved. The tailpipe (vent) should extend beyond the end of the pipe and not be easily moved.

d) A vent hose is attached to the tailpipe so that it leads downwind away from the job site. Its purpose is to vent any hydrocarbon vapors out of the pipe and away from the job site location.

e) A bond wire is clamped on the tail pipe and to the pipe itself. The purpose of the bond wire is to bleed off any static charges generated by flow through the vent and prevent an arc from occurring inside the pipe should the welder's stinger accidentally contact the vent tailpipe.

5 Lightning

5.1 General

The information in this section is based on the present state of the art of protection against direct-stroke lightning and indirect lightning currents. Perhaps the most significant property of lightning is its complexity. There is no such thing as a standard lightning stroke. Hence, the behavior of lightning phenomena can best be described and analyzed in statistical terms. In general, the statistical distribution of the characteristics of lightning varies with terrain, altitude, latitude, and time of the year. All these variations need to be considered in evaluating the risk posed by lightning and the design of any lightning protection system for a specific location. Even when all known precautions are employed, prevention or safe dissipation of direct-stroke lightning cannot be absolutely assured. In the case of indirect lightning currents, incendive sparks may occur in some segments of a system that use the best-known precautionary methods and devices. The methods discussed in this section have been generally successful but do not offer a guarantee of success.

Electrical storms involve the relatively slow movement of heavily charged clouds that set up an electrostatic field over a large surface area below the cloud. The field induces an opposite charge, which moves along with the cloud, on the surface of the earth, tanks, equipment, and other objects and usually occurs at a relatively slow rate. The charging current flows are relatively small and cause no damage. The charge is periodically neutralized almost instantaneously by a lightning strike that collapses the field. At that time, a heavy ground current flows toward the impact point caused by the neutralization of the ground charge.

Lightning is generally thought to propagate in the atmosphere by a streamer-leader mechanism. Leaders are highly conductive plasma channels that vary in length between 10 ft and 1000 ft (3 m and 300 m). The lightning stroke is composed of connected leaders or leader steps. The velocity of propagation of the leader is in the range of 900,000 fps to 328,000 fps (100,000 m/s to 275,000 m/s) and the electric charge in the channel can be between 3 coulombs to 20 coulombs. Because of the high charge concentration, the electric field strength can be sufficient to ionize air at a considerable distance, more than 30 ft (9 m) from the tip of the leader. Corona discharges from the end of the leader prepare the path for the next leader step. When the leader approaches ground level, the high electric field strength can cause initiation of a discharge from the ground upwards. This is the usual mechanism by which a lightning stroke completes its path to ground. However, the upward discharge does not always occur.

In addition to direct-stroke lightning, sparks or corona can discharge to the atmosphere at elevated points on equipment or between separate conductive objects that are in the path of a lightning-caused current. A more complete discussion of lightning protection can be found in NFPA 780.

5.2 Direct-stroke Lightning

Direct-stroke lightning can severely damage objects in its path as a result of heat energy and associated mechanical forces, as well as by direct ignition of flammable materials. The electric current and energy deposited by a lightning strike can be sufficiently high to melt thin metallic components and destroy electronic components if they are not designed to propagate to ground or divert the energy.

5.3 Indirect Lightning Currents

In addition to direct-stroke lightning, the abrupt change in the electrical field caused by lightning can cause secondary sparking at equipment that is relatively remote from the direct stroke. These induced charges or sparks usually occur when an insulated metallic body is present. The metallic body initially becomes charged by means of induction at a harmlessly slow rate through its high resistance to ground. When lightning strikes nearby, this induced charge is suddenly released in a discharge to ground, this can ignite a flammable mixture.

5.4 Protection of Specific Equipment Against Lightning

5.4.1 Inherent Grounding

Metallic tanks, equipment, and structures commonly found in the petroleum industry that are in direct contact with the ground (i.e. no nonconducting membranes) have proved to be sufficiently well grounded to provide for safe propagation to ground of lightning strokes. Supplemental grounding by means of driven ground rods neither decreases nor increases the probability of being struck, nor does it reduce the possibility of ignition of the contents. Supplemental grounding is necessary, however, where direct grounding is not provided.

Metallic equipment that does not rest directly on the ground but is connected to a grounded piping system is usually safe for propagation to ground of lightning strokes. Such equipment may require supplemental grounding to prevent foundation damage.

Metallic tanks, equipment, and structures that are insulated from ground should be adequately grounded and bonded. Such connections, when properly designed, provide a means of propagating the discharge to ground without causing damage to insulating materials that may be in the direct path of the stroke.

Structures made of insulating materials such as wood, plastic, brick, tile, or nonreinforced concrete are typically not inherently grounded for lightning protection. They can be protected from direct-stroke lightning by means of properly designed lightning protection systems.

See NFPA 70 and NFPA 780 for more information on grounding practices for lightning protection.

NOTE Ongoing research may provide guidance for alternative techniques for grounding tanks for lightning protection but is not available at this time.

5.4.2 Atmospheric Storage Tanks

5.4.2.1 Fixed-roof and Horizontal Tanks

Metal tanks with fixed metal roofs and horizontal metal tanks that are maintained in good condition are generally protected from damage by direct-stroke lightning and ignition of its contents, if all metal components are in electrical contact (i.e. bonded). However, there can be internal sparking at the liquid/gas interface within the tank if the tank suffers a direct lightning strike (see Annex E, References 21 and 22). See API 545, 1st Edition, Section 4.1. for additional information Most tank explosions that have occurred as a result of lightning strikes have been attributed to the following:

a) roof openings, such as gauge hatches, that have been left open;

b) vents that have not been protected by flashback devices, such as pressure vacuum vent valves;

c) corrosion holes or thinned areas of tank roofs.

The following precautionary steps can be taken by operating companies to minimize the risk associated with lightning strikes. Not all these precautions are practical in every situation. Therefore, each situation should be evaluated on its own merit.

a) Ensure all hatches are closed. To reduce the ignition hazard, some companies forbid the opening of gauge hatches during lightning storms.

b) Ensure roofs are in good condition (no holes, no excessively thin areas, no nonconductive patches, etc.).

c) Provide and maintain pressure vacuum valves or backflash protection in all vents. Pressure vacuum vents on tank openings prevent propagation of flame into a tank if escaping vapor ignites. Pressure vacuum vent valves, without flame arrestors, have been proved to satisfactorily stop a flame from propagating into the tank.

d) Stop tank movements (both filling and emptying) during electrical storms.

e) Provide and maintain inerting or gas padding.

Metallic tanks with fixed nonconducting roofs cannot be considered protected from direct-stroke lightning. However, these tanks can be provided with a metal covering, of adequate thickness [not less than $^{3}/_{16}$ in. (5 mm) per NFPA 780], that is in contact with the shell or provided with a lightning protection system.

Fully nonconductive tanks are inherently not capable of withstanding direct-stroke lightning. As a minimum, any conductive appurtenances need to be grounded for lightning protection. If the ignition of these tanks constitutes an unacceptable risk, the tanks can be protected by a lightning protection system or replaced by a metal tank.

5.4.2.2 Open Floating-roof Tanks

Fires have occurred in the seal space of open floating-roof tanks as a result of lightning-caused discharges. Ignition can come from a direct strike or from the sudden discharge of an induced (bound) charge on the floating roof. The induced charge is released when a charged cloud discharges to the ground somewhere in the vicinity of the tank.

Bonding of the roof is an effective defense to prevent ignition and fire due to a lightning strike. See API 545 for information recommended practices to for bonding between roof and shell.

Because a tight seal is also a very effective defense against lightning, an inspection program to ensure an adequately tight seal will prevent many incidents. Such an inspection program should also verify good shunt-to-shell contact.

Lightning-related explosions have occurred inside pontoons on floating roof tanks as a result of pontoon covers not being in place and a flammable atmosphere inside the pontoon. Risk of pontoon explosions can be reduced by:

a) providing mechanical hold down of the pontoon covers;

b) inspecting pontoon covers to ensure there is good metal-to-metal contact;

c) providing vapor tight pontoon compartments;

d) inspecting pontoons for the presence of flammable vapors or liquids on a routine basis.

The hazard of ignition increases if a floating roof is landed on its legs and a vapor space develops below the roof. This hazard can be minimized by not landing the roof on its legs during normal operation or during a thunderstorm and by avoiding initial filling during a lightning storm.

5.4.2.3 Internal Floating-roof Tanks

Internal floating-roof tanks with conductive steel roofs are inherently protected against internal ignitions from lightning induced sparking by the Faraday-cage effect. As a result, the internal floating roof does not require bonding to the shell or tank wall for lightning protection. See API 545, 1st Edition, Section 4.1 for additional information. However, the floating roof or cover still requires bonding to the shell for protection against electrostatic charges due to product flow.

Limited experience to date indicates that aluminum geodesic domes do not impose an increased risk.

Because internal floating roof tanks have open vents, it is important that the potential for a flammable atmosphere between the fixed roof and floating roof be minimized by:

a) providing a tight seal around the floating roof;

b) providing adequate venting in accordance with API 650,12th Edition, Appendix H;

c) avoiding landing the roof during normal operations (refloating the roof displaces the vapors into the vapor space);

d) avoiding initial filling of the tank during an electrical storm;

e) testing the vapor space for combustibles on a routine basis (in order to check the condition of the seal).

5.4.3 Pressure Storage

Metallic tanks, vessels, and process equipment that are designed to contain flammable liquids or gas under pressure do not normally require lightning protection. Equipment of this type is usually well grounded and is thick enough [not less than $^{3}/_{16}$ in. (5 mm) per NFPA 780] not to be punctured by a direct strike.

5.4.4 Tank Ships and Barges

In general, a steel ship or barge can be considered to be protected against damage from direct-stroke lightning if the masts and other projections are adequately grounded to the hull. On ships whose hulls are constructed of wood or other insulating materials, a ground connection from the mast or other projecting metallic structure to a copper plate below the water line should be provided. Radio antennas should be provided with a lightning arrestor or with facilities for grounding during electrical storms.

Ships and barges are subject to indirect induced currents and corona effects, which can cause sparking. It is advisable to suspend loading or unloading operations and to close all tank openings when severe lighting storms are in the vicinity.

See the OCIMF *International Safety Guide for Oil Tankers and Terminals* (*ISGOTT*) for specific information on effective lightning protection of tanks and barges.

5.4.5 Tank Trucks and Railroad Tank Cars

Experience over a number of years has indicated that tank trucks and tank cars are adequately protected from lightning provided that all hatches and all openings are closed. It is advisable, however, to suspend loading or unloading operations and to close all tank openings when severe lightning storms are in the vicinity.

5.4.6 Atmospheric Process Vents

Flashback protection or other means of prevention of flame propagation should be considered (based on a risk assessment) for atmospheric process vents where the potential exists for a flammable vapor release and ignition during a lightning storm. Weather covers over the vents need to be electrically continuous with the vent pipe.

5.5 Protection Against Direct-stroke Lightning

See Annex C for descriptions of available direct stroke lightning protection systems.

6 Stray Currents

6.1 General

The term stray current applies to any electrical current flowing in paths other than those deliberately provided for it. Such other paths include the earth, pipelines, and other metallic objects or structures in contact with the earth. A stray current may be continuous or intermittent, unidirectional or alternating, and is usually distributed among a number of available parallel paths in inverse proportion to the paths' individual resistances.

6.2 Sources and Limitations

Stray currents can accidentally result from faults in electrical power circuits. They may also be deliberate, as in the case of currents applied for cathodic protection of pipelines or other buried structures. Or currents may be inherent to a situation, such as the ground-return currents in some types of power systems and the galvanic currents resulting from corrosion of buried metallic objects.

Stray currents from power systems have no definable limits of voltage or current. It is unusual for the voltage to exceed that required for breaking down an air gap between fixed electrodes (see A.6.3). However, contacts made and separated can result in momentary and usually incendiary discharges or cases in which the potential, in sustained arcs, exceeds about 35 volts, which are always dangerous. Cathodic-protection currents have the same general character, except that the input voltage is comparatively low. The risk of an incendiary spark is still significant.

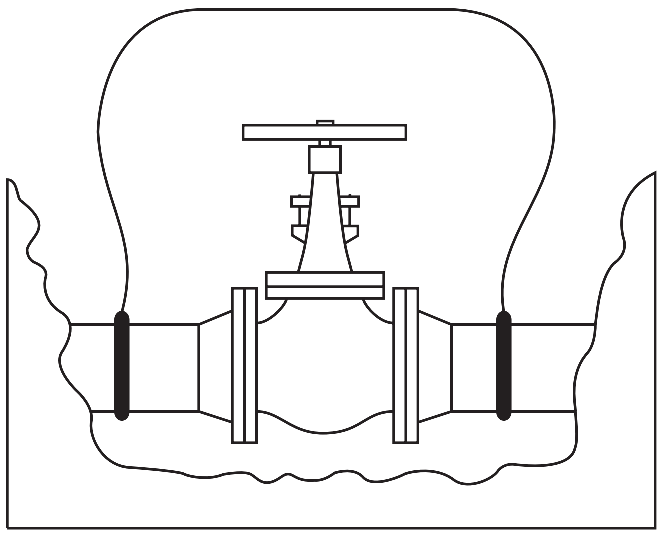
Another source of stray currents is the galvanic action resulting from the contact of metals with the soil. Such currents may travel along a buried pipeline from a point of contact with one type of soil to a point of contact with a different type of soil. The potentials produced by galvanic actions are strictly limited and cannot exceed 15 volts. The critical factors, however, are the particular circuit parameters of voltage, current, and resistance that can result in a current that, when interrupted, can result in an incendive arc.

Field measurements can be made to disclose the presence, direction, and magnitude of stray currents. Unless there has been some visible evidence such as accelerated corrosion or discharge, tests are unlikely to be made at all points where a discharge might be significant. Therefore, precautions against the presence of electrical discharges are recommended at points where certain types of work are to be done and where a flammable mixture might exist.

6.3 Protection of Specific Operations Against Stray Currents

6.3.1 Pipelines

If a gas or light oil pipeline, which handles heavy stray currents, is severed, arcing may occur at the point of separation, creating an ignition hazard. Where stray currents are known or suspected, a short, heavy-gauge bond wire or jumper should be connected across the point where the line is to be separated. The procedures to be employed when a line is opened are identical to those required when a valve or spool is removed or inserted (see Figure 11). To be effective, the bond must have a low electrical resistance (typically less than 2 ohms). The wire must be attached to the pipe in a way that provides minimal electrical resistance.



NOTE To remove or replace a valve or spool when hydrocarbons and stray currents may be present, the following steps should be taken.

1. Attach the bonding cables.
2. Remove the valve or spool (or open the line). (Step 1 and Step 2 should be reversed when a valve or spool is installed.)
3. Remove the bonding cable during the time the line is open, provided the bypass connection is broken at a location where flammable mixtures are not present.

Figure 11—Stray Current Bypass

6.3.2 Spur Tracks

As a result of stray currents, pipelines that serve tank car loading and unloading spots located on spur tracks may be at a different potential from that of the rails. Stray currents may flow in the pipelines or in the rails. The usual protection against stray current arcs, which can result when tank car connections are broken, is to bond at least one rail to the pipelines that serve loading or unloading facilities. This bond should be a permanent electrical connection that consists of one No. 4 AWG or no less than two No. 6 AWG wires (see Figure 7). Insulated pipe joints between the loading or unloading facilities and the connecting yard pipelines provide additional protection against stray currents that may exist in the rails and flow to the piping system.

Spur tracks may connect with electrified main lines, cross electric railway tracks, and in some instances, be equipped with rail-circuit signal systems. In all such circumstances, insulating couplings should be placed in the rail joints of the spur track so that the track will be completely insulated from the source of any return rail currents (see Figure 12). The insulating joints should not be bridged by rail equipment during the transfer of flammable liquids.

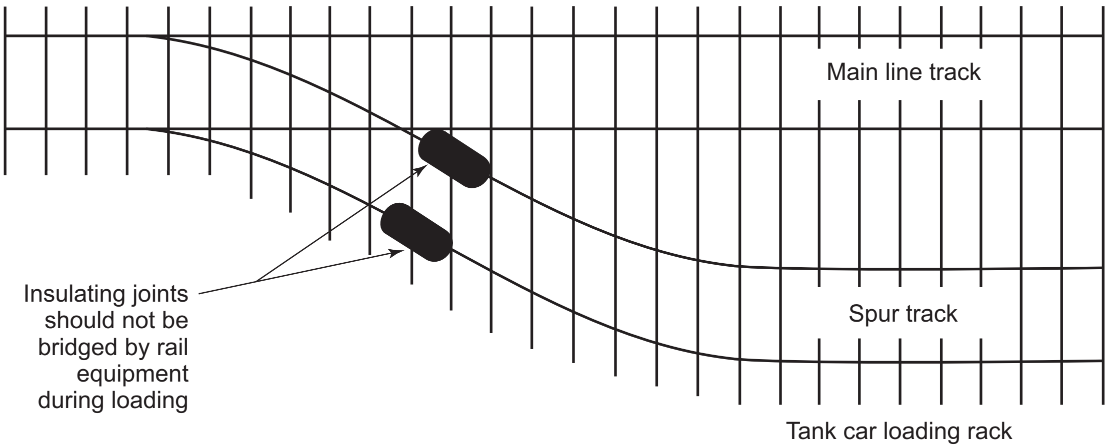


Figure 12—Isolating Spur Tracks from Main-line Stray Current Sources

6.3.3 Wharf Lines

If stray currents are present in wharf piping, connecting and disconnecting a ship's hose may produce arcs because the resistance of the ship's hull to ground (water) is exceedingly low.

In such circumstances, the stray currents in the ship's hose can be reduced in magnitude by providing a low resistance ground for the wharf piping. However, where cathodic-protection facilities are operating to prevent corrosion of the wharf structure or the ship's hull, pipe grounding can increase the stray currents in the ship's hose.

Insulating flanges in the pipe risers to the hose (or loading arm) connections break the conductive path and provide the best assurance against arcing at the point of connection and disconnection of the hose (or loading arm). Insulating flanges at the shore end of wharf piping are effective where stray currents arise from onshore facilities. Insulating flanges are employed at both locations to prevent arcing at the connections and to prevent the flow of stray or cathodic-protection currents between the wharf and shore piping. If there are insulating flanges at both the shore and pipe riser, the pipe between the shore and the riser must be grounded. In any case, a conductive path between the riser and the ship must not exist. Where flexible hose strings connect the ship and wharf piping, an alternative to the insulating flange is to include one length of nonconductive hose in each string to block current flow between the ship and the wharf. When insulation is used to prevent stray currents, no electrically conductive objects, such as metal flanges, should be isolated in the cargo lines as they could accumulate static electricity. An example of this would be isolated flanges or couplings if more than one nonconductive length of hose were used. (See OCIMF *International Safety Guide for Oil Tankers and Terminals,* Sections 3.2.2, 11.1.13.8, and 17.5 for more information.)

In the past, some companies bonded wharf pipelines to the ship by means of bonding cables. This practice is inconsistent with both *ISGOTT* and API 2003 recommendations. The U.S. Coast Guard puts the issue clearly, stating "It is important to note that cargo transfer piping must be insulated from the land-side terminal since electrical potential may differ from that of the vessel due to stray current or cathodic protection of the pier. Insulating flanges, joints, or sleeves are sometimes used to divide the cargo hoses into electrically isolated halves onboard and shore side. Each half is bonded and grounded to its respective base potential."

Figure 13 illustrates typical methods of protection against stray currents at wharves. Stray currents can also be present in the piping associated with a vapor recovery system and the same precautions need to be taken as those for the product transfer piping.

Marine vapor recovery systems are addressed in a manner similar to loading lines. The facility vapor connection must be electrically insulated from the vessel vapor connection in accordance with 6.10 of the OCIMF *International Safety Guide for Oil Tankers and Terminals*.

6.3.4 Cathodic-protection Systems

A special engineering study is required when cathodic-protection systems are employed to protect a facility against corrosion. The study must consider the normal operational safety of the installation and any unusual circumstances likely to be encountered during construction or maintenance operations.

Sometimes the insulating devices and special circuits (anodes, buried cables, etc.) used by the corrosion engineer present an additional fire control problem. Therefore, in addition to the precautions recommended here, it is advisable to consult someone familiar with the arrangement of the cathodic-protection system (including power sources and underground cables) prior to undertaking pipeline work or excavation in the vicinity. De-energizing an impressed-current cathodic-protection system will not immediately remove the potential because such currents will persist for some time afterward as a result of the polarization effects on the buried metallic structures and piping.

In the case of cathodically protected steel wharves, bonding cables can be eliminated-provided the hose risers are equipped with insulating flanges to prevent passage of cathodic currents between the ship's hull and the wharf structure. Insulating joints should be located where they cannot be bypassed or bridged. A resistance as low as a few ohms is sufficient to reduce the current to a safe level, but the measured value should be substantially higher, because a very low measured resistance may indicate damage to or deterioration of the insulation. Other possibilities for metal-to-metal contact and points for stray current flow between the ship and the wharf should be evaluated for the possibility of arcing in the presence of flammable vapors.

In the case of truck and tank car loading racks with connecting pipelines that are cathodically protected, special consideration may be required in the location and sizing of bond wires.

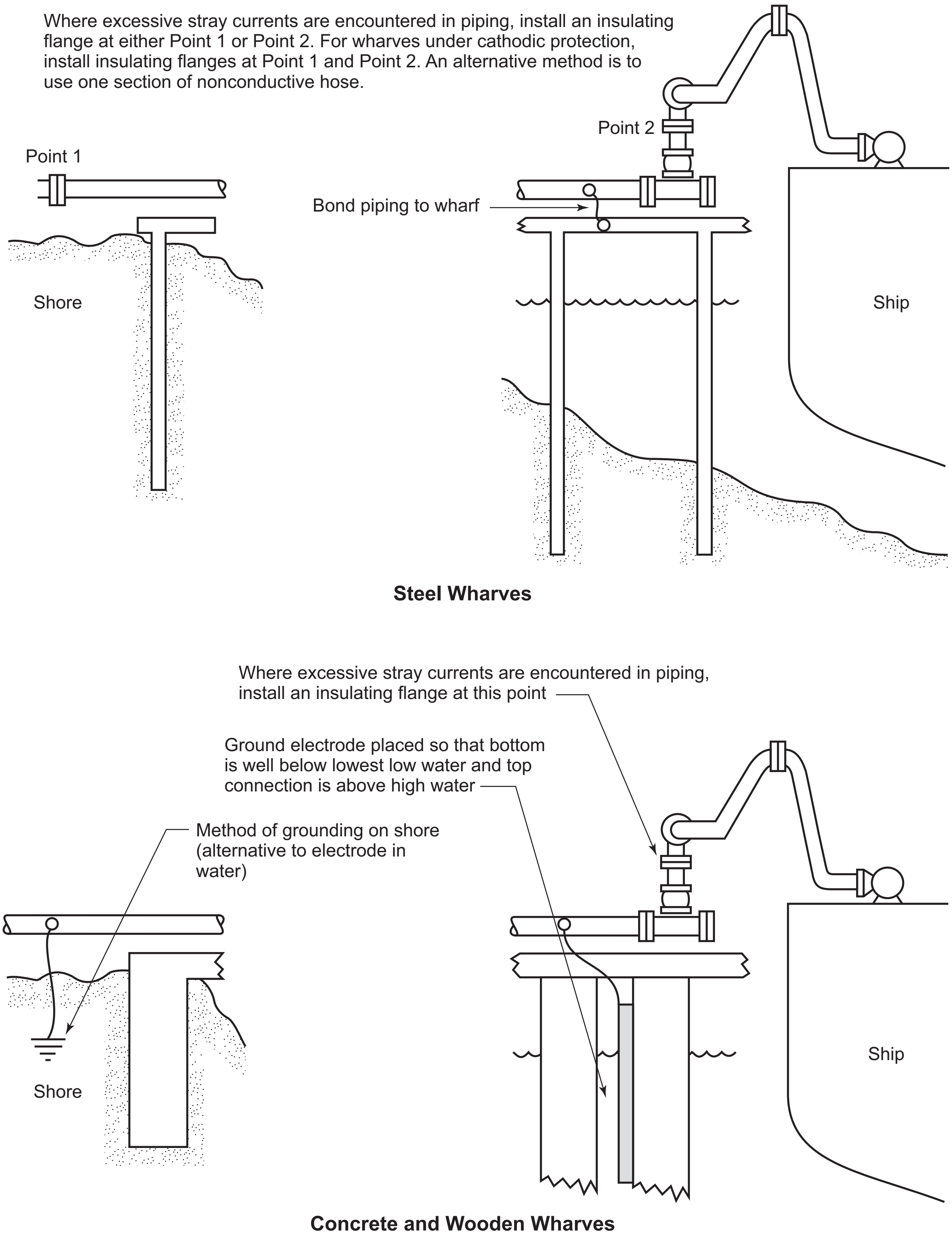


Figure 13—Bonding, Grounding, and Insulating at Marine Wharves

Annex A
(informative)

Fundamentals of Static Electricity

A.1 General

The study of static electricity is concerned with the accumulation of electrical charges on materials, the mechanisms by which these charges are generated, and the processes of dissipating accumulated charges. The flow of electricity during generation and accumulation is small, in the range of millionths of an ampere, but the potential differences involved may amount to thousands of volts. For this reason, resistances of less than 1 megohm act as short circuits. A primary manifestation of static electricity is the discharge or sparking of the accumulated charges. Because static electricity is different from electric power systems, the instruments and techniques for measurement are unique (see Annex B).

A.2 Generation of Static Electricity

Static electricity is generated by the separation of like or unlike bodies. Both positive and negative electrostatic charges always occur in pairs and are separated and become evident when two bodies that have been in contact are separated. For significant charges to be developed, the bodies must become and remain insulated with respect to each other so that the electrons that have passed over the boundary surface or interface are trapped when separation occurs. Insulation may occur because the bodies are completely physically separated or because at least one of the bodies is an insulator. In the latter instance, charging may arise from friction or rolling contact between bodies. Examples of static producers are shown in Figure A.1.

Of more importance to the petroleum industry is the static charge resulting from contact and separation that takes place in a flowing liquid. Prior to flow, the liquid contains equal quantities of positively and negatively charged ions and is electrically neutral. However, ions of one sign are preferentially adsorbed by the surface of the container or pipe, leaving a surplus of ions of the opposite sign in the liquid at the interface. When the liquid flows, charging occurs because the adsorbed ions are separated from the free ions, which are carried into the body of the liquid by turbulence. Figure A.2 shows how the charges are mixed with the liquid and carried downstream. The opposite charge is usually conducted through the metallic pipe wall in the same direction because of the natural attraction between opposite charges. Impurities (water, metal oxide, and chemicals) increase the static-generating characteristics.

The flow of electricity caused by the entrainment of charged particles in the flowing fluid is known as the streaming current. If this charged stream enters a metal container or tank, charge separation will be induced on the tank wall. A charge equal in magnitude to the fluid charge, but of opposite sign, will be induced on the inside surface of the tank, and a charge of the same sign as the incoming stream will be left on the outside surface of the tank. If the tank is grounded, this charge on the outside surface will flow to ground. The charge on the inside will remain, held by the attraction of the charge in the fluid. Ultimately, the charge in the fluid and on the wall will come together by movement of the charge through the fluid (see Figure A.3).

Strong electrostatic fields may also be generated by droplets or solid particles settling in a medium of low conductivity or by agitation of such particles within the medium. If a liquid in a tank containing impurities is subject to turbulence, increasing ionization and subsequent separation of ions can result in electrostatic charging within the body of the liquid. Such charging may cause significant variations in voltage within the liquid or on the liquid surface.

A.3 Rate of Generation

The electrostatic generating mechanism in fluid flow is primarily related to the rate of flow, material turbulence, and surface area of the interface. The rate of electrostatic generation in a pipeline or hose increases to a maximum limiting value as the length of the pipe or hose increases. The large surface area and small pore openings of

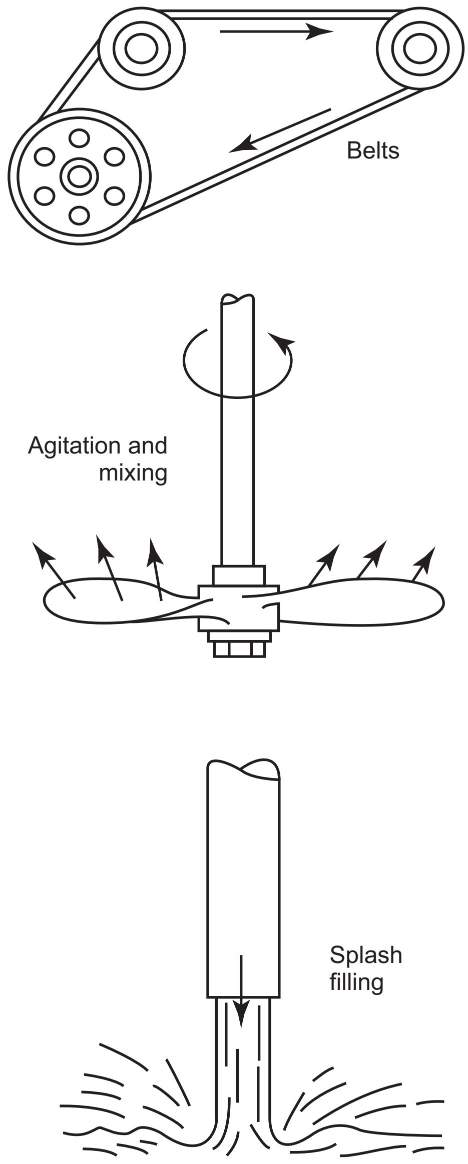


Figure A.1—Static Procedures

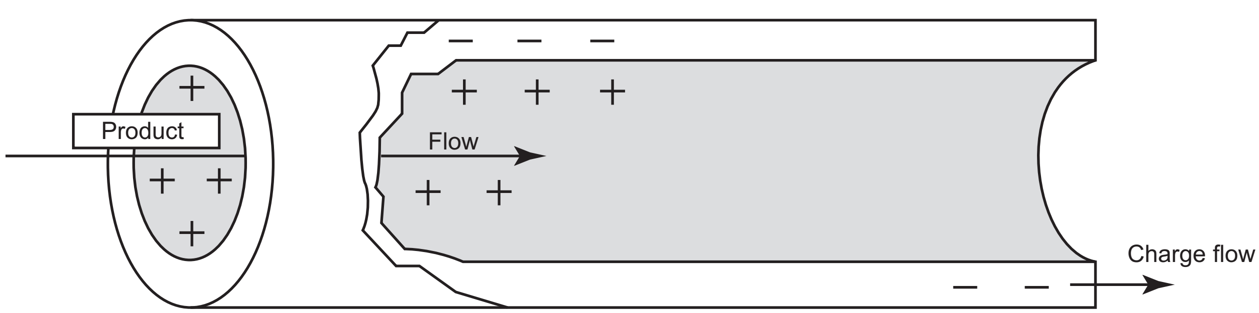


Figure A.2—Charge Separation in a Pipe

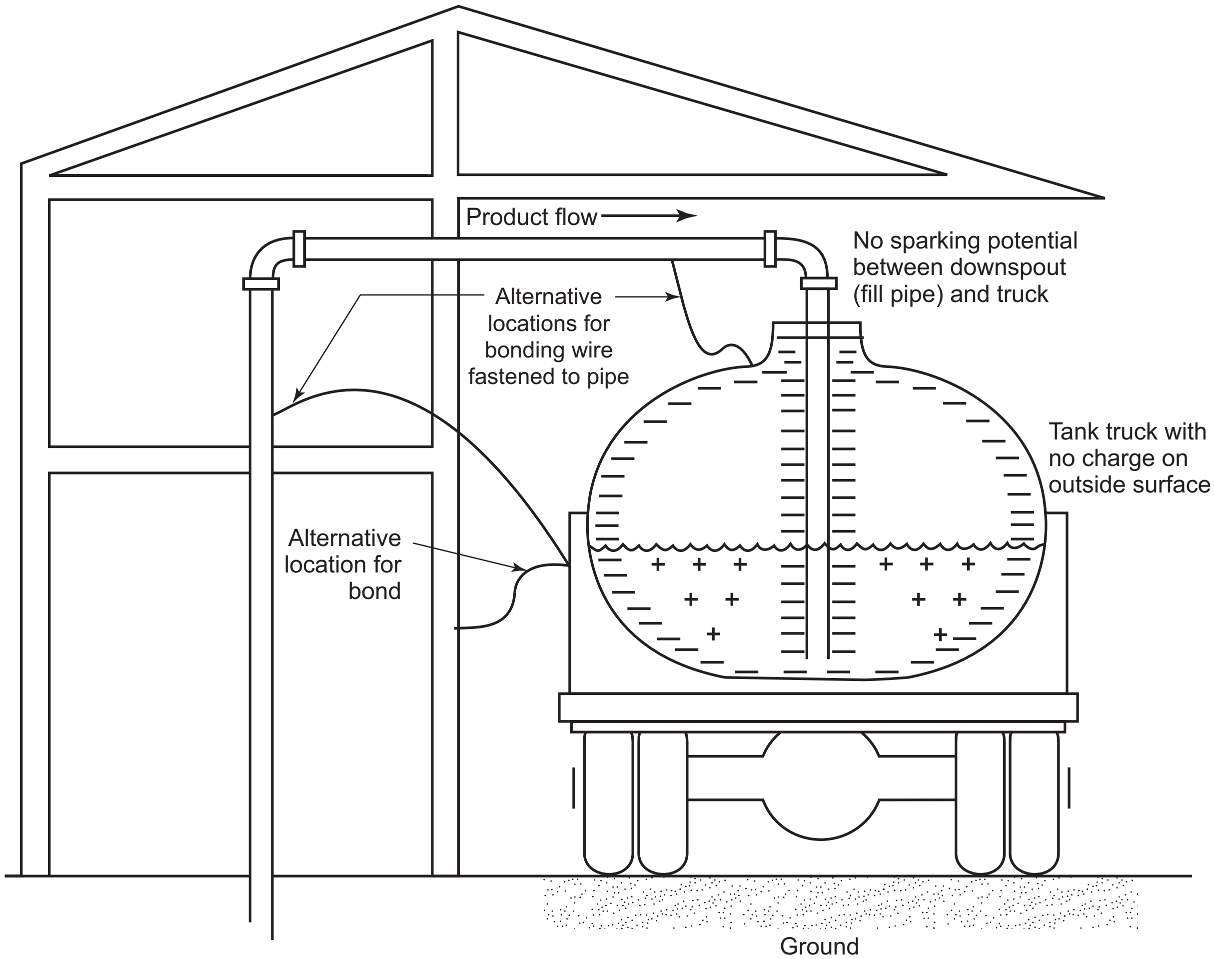


Figure A.3—Charge Movement Through a Liquid

Micropore filters result in intimate contact between all of the fuel and the filter surface, causing the filters to be prolific generators of electrostatic charge.

A low-conductivity liquid will generate static charges when pumped through a pipe and accumulate charge where it collects in a tank or vessel. The magnitude of the charge developed is a complex function of the fluid's composition and its velocity through the pipe. For most liquids, the more quickly the liquid is moved, the greater the charges that will be generated. As soon as the liquid is charged, however, a voltage builds up and the charge tends to dissipate. The rate of dissipation will increase with increased voltage or with increased fluid conductivity.

When a fluid is pumped through a pipe at a constant velocity, the liquid's charge density will stabilize at a value at which the charge generation is balanced by the charge dissipation (see Figure 9). If this liquid is conducted into a smaller pipe, the liquid velocity will increase. This increases the liquid's rate of charge generation. In the smaller pipe the charge density and streaming current tend to increase but the maximum potential in the pipe tends to decrease. As fluid travels down the pipe, the rate of charge leakage also increases and (at some finite distance down the pipe) the liquid's charge density stabilizes at some higher value. The potential due to accumulation in a tank downstream of this smaller pipe will increase because of the higher delivered charge.

If the pipe size is increased, the reverse occurs and the liquid's potential stabilizes at a lower value.

A.4 Accumulation of Static Electricity

The generation of electrostatic charge by itself does not produce discharges. A high electric potential and electric field is required for a discharge to occur. This will only happen when the electrostatic charge that has been generated accumulates. Hazardous electrostatic charges can only accumulate on bodies that are insulated from each other and from ground; otherwise, the charges will dissipate (recombine with their counterparts) as fast as they are formed.

In cases where charge dissipates by moving across the surface of equipment or other solid bodies, humidity can have a significant effect by changing the conductivity of the surface. During periods of normal humidity (50 % or more), an invisible film of water provides an electrical leakage path over most solid insulators. Where charges dissipate by moving through liquids or solids or over the surface of a liquid, the humidity has no effect.

Electrostatic sparks from insulated conductors are among the most incendive discharges that can occur. The amount of electrostatic charge that can accumulate on an insulated body depends on the rate at which the static charge is being generated and the resistance of the paths through which the charge dissipates. For practical purposes, hazardous electrostatic charge accumulation will not occur if the resistance to earth is less than one million ohms.

The most hazardous electrostatic situation in a petroleum operation is the buildup of a charge on an isolated (ungrounded) piece of conductive equipment. When charge is stored on such a conductive object, almost all of the charge can be drained in a single spark and the energy in the spark is usually many times that required to ignite flammable mixtures. For this reason it is imperative to keep conductive objects bonded and grounded at all times.

A.5 Conductivity and Electrostatic Charge Relaxation in Liquids

Except for mists, electrostatic accumulation is not significant when the conductivity of the liquid exceeds 50 pS/m and the fluid is handled in conductive containers. Above this value, charge generation occurs (as a result of, for example, flow through a filter), but the charges recombine as fast as they are separated. Hence, no net accumulation occurs.

Electrostatic charge accumulation may be significant when the conductivity of the liquid is below 50 pS/m. All commercial hydrocarbon products contain minute amounts of ionizable material. When the hydrocarbon flows past a surface, such as a pipe wall or filter, some of the ionic material remains behind adsorbed on the surface. Usually, the surface retains more ions of one sign than the other. Thus, the flowing hydrocarbon acquires an electrical charge because of the electrical imbalance of ionic material. When left at rest, the hydrocarbon liquid gradually returns to electrical neutrality by exchange of ionic material with its surroundings such as the pipe or vessel wall. This process is called “charge decay” or “charge relaxation.” The speed at which equilibrium is reached is determined by the liquid physical properties.

For liquids with a conductivity greater than 1 pS/m, charge relaxation proceeds by exponential or “ohmic” decay. This so-called “ohmic” theory of charge relaxation has been experimentally confirmed for this category of hydrocarbon liquids, and exponential charge relaxation is described by the following equation:

Hence, for liquids that follow “ohmic” relaxation, the relaxation rate depends strongly on the conductivity. The lower the conductivity, the slower the relaxation will be. The ratio of dielectric permittivity to the liquid conductivity is referred to as the “relaxation time constant.” The relaxation time constant is the time for a charge to dissipate to e^{-1} (approximately 37 %) of the original value, if charge relaxation follows exponential decay. It gives an indication of the electrostatic accumulation relaxation time constant of typical liquids.

$$Q_t = Q_o e^{-t\kappa/\varepsilon\varepsilon_o}$$

where

Q_t is the charge density in coulombs per cubic meter;

Q_o is the initial charge density in coulombs per cubic meter;

e is the base of natural logarithms = 2.718;

t is the elapsed time in seconds;

κ is the liquid conductivity in siemens per meter;

ε is the dielectric constant for the liquid;

ε_o is the electrical permittivity of a vacuum = 8.85×10^{-12} farads per meter.

Liquids with conductivity less than 1 pS/m do not, in practice, relax charges as slowly as ohmic relaxation would suggest. As explained in Annex D, reference 1 (Bustin, et al), when such liquids are highly charged, the usual relationship described by Ohm's law does not apply; instead, for these liquids, charge relaxation proceeds by hyperbolic decay. The hyperbolic theory of charge relaxation has been experimentally confirmed for low conductivity hydrocarbon liquids, both in small-scale laboratory experiments and in full-scale tests. Hyperbolic charge relaxation is described by the following equation:

$$Q_t = \frac{Q_o}{(1 + (\mu Q_o t)/\varepsilon\varepsilon_o)}$$

where

Q_t is the charge density in coulombs per cubic meter;

Q_o is the initial charge density in coulombs per cubic meter;

μ is the ion mobility in square meters per volt-second, about 1×10^{-8} m^2/V-sec for charged distillate;

t is the elapsed time in seconds;

$\varepsilon\varepsilon_o$ is the electrical permittivity for the liquid in farads per meter.

Hence, for low conductivity liquids, charge relaxation is dependent only on the initial charge density, Q_o, and ion mobility, μ. The conductivity of the uncharged liquid is not a factor. In addition, charge decay is not very sensitive to initial charge density when the initial charge density is greater than about 100 micro-coulombs/m^3.

Some representative conductivity and relaxation data are presented in Table A.1 showing a range for materials including those which do, and those which do not, follow "ohmic" relaxation.

A more recent review of relaxation time for low conductivity fluids is included in Annex A of Laurence G. Britton's *Avoiding Static Ignition Hazards in Chemical Operations*. Here he cites 2 pS/m as a transition point from ohmic to hyperbolic relaxation.

A.6 Static Discharge

A.6.1 General

In practice, electrostatic charges constantly leak from a charged body because they are always under the attraction of an equal but opposite charge. This characteristic is called charge relaxation, and because of this, most static sparks are produced only while the generating mechanism is active. It is possible, however, for charges generated during movement of some refined petroleum products to remain for a short time after the fluid has stopped moving because of the fluid's insulating qualities.

Table A.1—Conductivity and Relaxation Time Constant of Typical Liquids

Product	Conductivity pS/m	Relaxation Time Constant seconds
Benzene	0.005	»100
Xylene	0.1	210
Toluene	1	21
Gasoline	10 to 3000	1.8 to 0.006
Jet fuel without conductivity additives	0.5 to <50	36 to >0.36
Diesel	0.5 to <50	36 to >0.36
Gas oil	<50	>0.36
Lube oil (base)	0.1 to 1000	180 to 0.018
Lube oil (blended)	50 to 1000	0.36 to 0.018
Heavy "black" fuel oils	50 to 1000	0.36 to 0.018
Asphalt	>1000	<0.018
Crude oil	>1000	<0.018
Ref: SCE No. 8984 For additional compounds see NFPA 77		

A.6.2 Sparks and Arcs

Although popular usage does not distinguish between sparks and arcs, a technical difference is recognized. A spark results from the sudden breakdown of the insulating strength of a dielectric (such as air) that separates two electrodes of different potentials. This breakdown produces a transient flow of electricity across the spark gap and is accompanied by a flash of light, which indicates a high temperature. In contrast to a spark, an arc is a low-voltage, high-current electrical discharge that occurs at the instant two points, through which a large current is flowing, are separated. Technically, electrostatic discharges are always sparks.

A.6.3 Sparking Potential

For static electricity to discharge as a spark, the voltage across the spark gap must be above a certain magnitude. In air, at sea level, the minimum sparking voltage is approximately 350 volts for the shortest measurable gap. Larger gaps require proportionately higher voltages; the actual voltage depends on the dielectric strength of the materials (or gases) that fill the gap and on the geometry of the gap. For dry air and large gaps, the dielectric strength is approximately 3×10^6 volts/m.

In the petroleum industry, spark gaps assume many forms and appear at various locations. For example, a spark gap may be formed between a tank vehicle and the overhead filling downspout if they are not bonded together or in metallic contact. In this case, a static potential difference is developed between the tank vehicle and the downspout as a result of the static charges generated during the flow of the product into the compartment.

The potential developed is related to the amount of charge on a body and to the capacitance of the body with respect to its surroundings. The relationship is expressed as follows:

$$V = Q/C$$

where

V is the potential in volts;

Q is the charge in coulombs;

C is the capacitance in farads.

Because the capacitance of a body with respect to its surroundings depends on its size and position, the same charge will not always result in the same voltage, and hence sparking may or may not occur. For instance, a large steel plate supported parallel to the earth's surface and insulated from it has a larger capacitance with respect to the earth than does a smaller plate mounted in a similar manner at the same distance from the earth. If the same charge is placed on both plates, the larger plate will have a lower voltage with respect to ground than will the smaller plate. Thus, the smaller plate might spark to the earth (discharge), but the larger plate would not have sufficient voltage for sparking.

Under the continuous influence of a charge-generating mechanism, the voltage of an insulated body continues to grow. Because no insulation is perfect, as the voltage becomes greater, the rate at which the charge leaks through the insulation increases. At some voltage, the leakage of charge will equal the rate at which the charge is being placed on the insulated body and a stable condition will be reached. If this stabilized voltage is below the required sparking potential, no sparking will occur. If the stabilized voltage is above the sparking potential, sparking will occur before stabilization is reached. For this reason, individual and discrete spark discharges are sometimes observed under conditions of continuous electrostatic generation. As charges are deposited on a body, the voltage begins to grow; then, if the charge leakage through the insulation is not rapid enough, sparking potential is reached. The spark then discharges from the body and the voltage immediately drops. At this point, the entire process is repeated.

A.6.4 Ignition Energy

The mere fact that a spark results from high voltage does not mean that ignition of a flammable mixture will occur. For combustion to be initiated, sufficient energy must be transferred from the spark to the surrounding flammable mixture. The energy that is stored and available from a capacitive discharge is related to voltage and capacitance by the following formula:

$$E = 0.5CV^2$$

where

E is the energy in joules;

C is the capacitance in farads;

V is the potential in volts.

Experiments under the most favorable conditions have ignited petroleum vapor-air mixtures at approximately 0.25 millijoule. The energy requirement increases as the mixture's composition approaches the lean or rich sides of the flammable range; it is at a minimum near the stoichiometric mixture.

The energy requirement is also increased by other factors that tend to decrease the availability of the stored energy to the flammable mixture. These factors include the following.

a) A portion of the energy will be dissipated in a resistive portion of the discharge circuit and will not be available at the spark gap.

b) The electrode across which the sparking occurs will be of a shape and material such that a portion of the energy in the spark will be wasted in heating the electrode and will not be available to heat the material in the gap. This is more pronounced with short gaps and is known as the electrode's quenching effect.

c) The spark gap may be so long that the energy is distributed over too long a path to heat the mixture to ignition. Gas temperature and pressure may also increase or decrease the requirement for ignition energy.

Practical experience indicates that under normal conditions, it takes substantially more energy than the experimentally determined minimum to ignite flammable mixtures. This accounts for many situations where sparks have been observed but ignition has not. When the gap distance is smaller than that required for a 1500-volt spark-over, static potentials of less than 1500 volts are not likely to cause ignition because of the quenching effect of electrodes.

Sparks that release enough energy to result in the ignition of flammable vapors are known as incendive sparks. Sparks that do not release enough energy are known as nonincendive sparks. A form of discharge, known as corona, is manifested by a violet glow at locations of high field strength and results from ionization of the gas molecules under electron impact. Corona is usually nonincendive in the presence of flammable hydrocarbon vapor-air mixtures. However, the presence of corona is indicative of electrostatic charging and may be followed by an incendive spark discharge.

A.7 Ignition by Static Electricity

For an electrostatic charge to be a source of ignition, the following four conditions must be met:

a) a means of generating an electrostatic charge must be present;

b) a means of accumulating an electrostatic charge capable of producing an incendive spark;

c) a means of discharging the accumulated electrostatic charge in the form of an incendive spark (that is, a spark gap) must be present;

d) an ignitable vapor-air mixture must be present in the spark gap.

A.8 Static Control

A.8.1 General

Ignition hazards from static sparks can be eliminated by controlling the generation or accumulation of static charges, the discharge of static charges, or the vapor-air mixture at points where static charges can be discharged as sparks. Several basic and effective steps that can be taken to prevent static ignition are discussed in A.8.2 through A.8.8.

A.8.2 Bonding

Sparking between two conducting bodies can be prevented by means of an electrical bond attached to both bodies. This bond prevents a difference in potential across the gap because it provides a conductive path through which the static charges can recombine. Therefore, no spark can occur. This is shown in Figure A.4, Figure A.5, and Figure A.6, which also show the relationship between voltages and assumed values of charge and capacitance.

Static bond wires are usually comparatively large because of mechanical considerations; bond wire resistances are therefore low. Such low resistances, however, are not needed for static dissipation because electrostatic currents are usually on the order of microamperes. A bond resistance as high as 1 megohm is still adequate for these small electrostatic currents because the resultant voltage difference appearing across the bond wire terminals is too low for sparking.

NOTE Orders of magnitude lower resistance are required for protection against higher amperage stray currents.

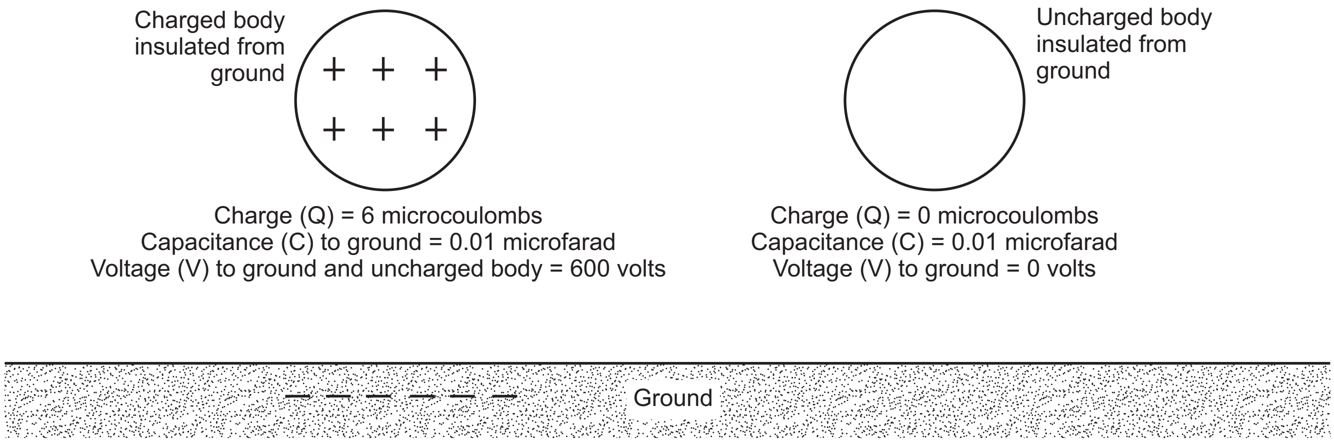


Figure A.4—Charged and Uncharged Bodies Insulated from Ground

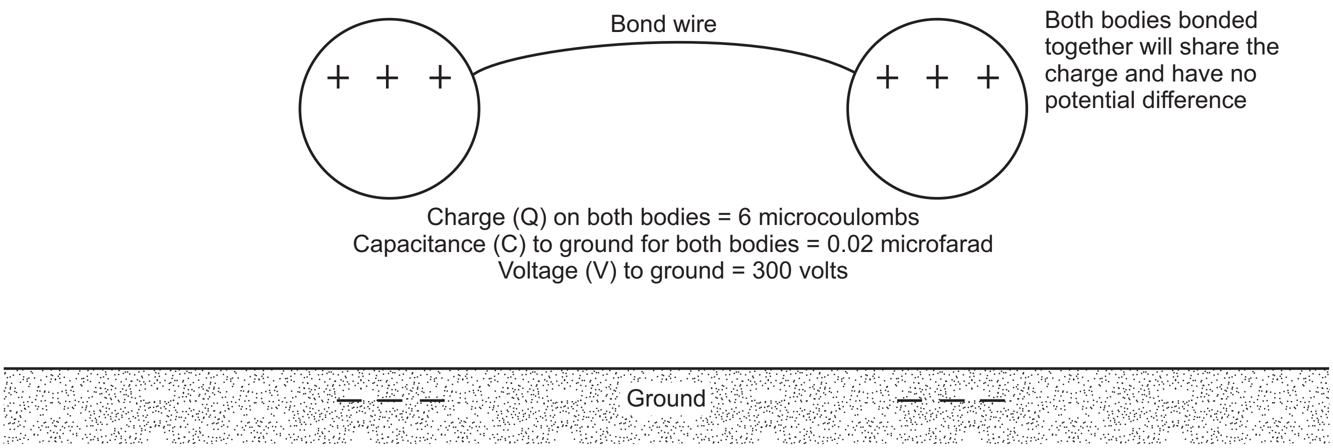


Figure A.5—Both Insulated Bodies Share the Same Charge

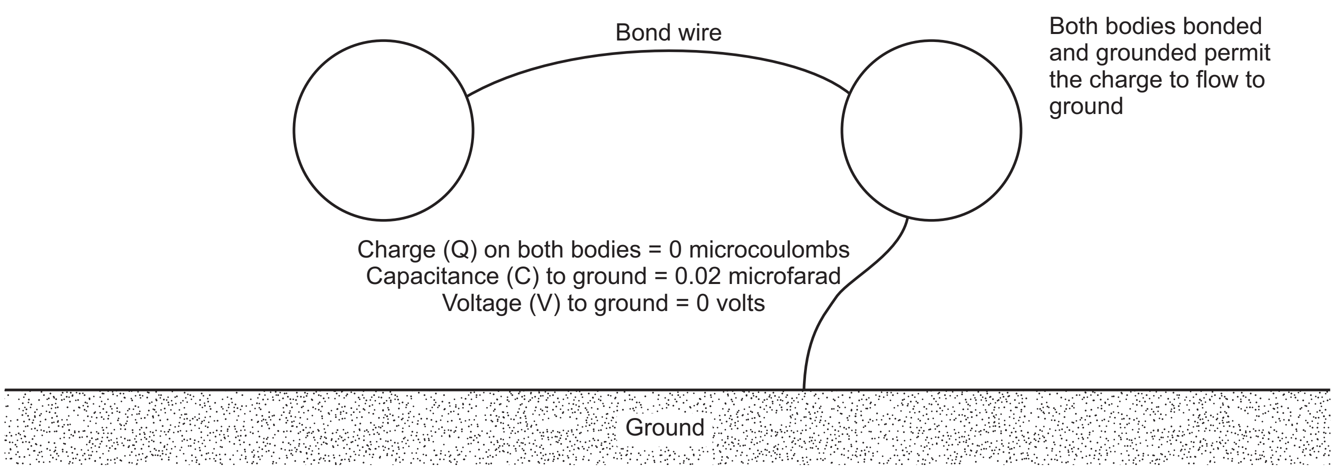


Figure A.6—Both Bodies are Grounded and Have No Charge

Bolted connections within the bond wire or at the bond wire terminals are adequate for static dissipation; soldered or brazed connections are unnecessary. The parts of a metallic fill-pipe assembly form a continuous electrically conductive path, and bond or jumper wires are not normally needed around flexible or swivel joints. Tests and experience have shown that resistance in these joints is normally low enough to prevent the accumulation of static charges. However, it is wise to check the manufacturer's specification for such joints because a few are fabricated with insulated surfaces. In addition, there have been cases of deterioration in service. Hence, periodic testing of conductivity is warranted. Conventional U clamps or other equivalent means of supporting riser pipes on metallic loading racks provide an adequate conductive path and permit one end of a bond wire to be fixed to the metallic loading rack rather than directly to the loading piping (see Figure A.3).

When put into service, new bonding systems typically have very low resistance, usually below 1 ohm. When auditing in-service installations static electricity experts generally consider that anything greater than 1 ohm for the total system resistance probably should be investigated further. Testing resistance across individual bonding connections may identify potential areas of concern.

Using insulated flanges to separate potentially charged bodies is used at wharves (see 6.3.3). U.S. Coast Guard recommendations put the issue clearly, stating "It is important to note that cargo transfer piping must be insulated from the land-side terminal since electrical potential may differ from that of the vessel due to stray current or cathodic protection of the pier. Insulating flanges, joints, or sleeves are sometimes used to divide the cargo hoses into electrically isolated halves—onboard and shore side. Each half is bonded and grounded to its respective base potential." The ship's metal hull is grounded through the water and the loading arms through ground cables.

A.8.3 Grounding

The earth may be used as part of the bonding system. Where the only gaps over which hazardous static sparks can occur are between an insulated object and a grounded object, such as between electrically insulated vessels and grounded piping, the electrical insulation can be bypassed by grounding the vessel. This will prevent the accumulation of a static charge on the vessel. However, grounding of a container or tank cannot prevent the accumulation of charges in a low conductivity liquid in the container (see Figure A.3).

A.8.4 Reducing Static Generation

The voltage on any body receiving a charge is related to both the rate of static generation and the rate of static dissipation (see A.6). This voltage can be prevented from reaching the sparking potential by restricting or reducing the rate of static generation. In the case of liquid hydrocarbon products the rate of generation can be reduced by decreasing or eliminating the conditions or activities that produce static. Reducing agitation by avoiding air or vapor bubbling, reducing flow velocity, reducing jet and propeller blending, and avoiding free falling or dropping of liquid through the surface of stored product will decrease or eliminate the generation of static. Electrostatic charging is also reduced by preventing droplets of water or other particulate matter from settling through the body of the liquid.

A.8.5 Increasing Static Dissipation Using Additives

A charge on the liquid will dissipate over time at a rate that is a function of the liquid's conductivity. Charge dissipation can be improved by:

— increasing the liquid conductivity through the use of SDA, previously referred to as anti-static additives (to a conductivity not less than 50 pS/m, but for practical purposes, 100 pS/m); or

— by retaining the liquid in an enclosed pipe or relaxation tank at low turbulence to provide more time for the charge to dissipate.

NATO and U.S. (MIL-DTL-83133E-1999) specifications for aircraft kerosene-type turbine fuel calls for conductivity additive to be added to provide a range of 50 pS/m to 700 pS/m depending on fuel grade.

When SDAs are used, it is preferred that the additive be introduced at the beginning of the distribution train. However, the resulting increased conductivity can be reduced significantly by dilution in the shipment/distribution system and by absorption as a result of passage through clay filters. (Not only does this remove additives but it also can impair filter flow.) In addition, some additives used in the past have been water-soluble.

Introducing the SDA at the final distribution point (such as at a loading rack) alleviates the dilution/absorption concerns. However, the presence of additive in the final product is less certain due to the potential for additive injection system failure or variability in conformance to local procedures.

Regardless of where in the distribution system an additive is introduced, if this is considered part of the static protection system, it is incumbent on the operator to verify that an adequate amount of additive is present in the final product. Hence, the operator must have systems in place (instrumentation, analyzers, testing, etc.) at all the critical points in the system to ensure and verify that adequate increased conductivity is achieved.

A.8.6 Controlling the Environment

When static discharge cannot be avoided by bonding, grounding, reducing static generation, or increasing static dissipation, ignition can be prevented by excluding ignitable vapor-air mixtures where the spark may occur. This is particularly difficult in the case of a flammable petroleum liquid whose vapor pressure produces ignitable mixtures at handling temperatures. However, a vapor-air mixture cannot be ignited unless the vapor-to-air ratio lies within certain well-defined limits, called the lower and upper flammability limits. The accepted values for various petroleum products are shown in the U.S. Bureau of Mines Bulletin 627 and NFPA *Fire Protection Guide to Hazardous Materials* which includes the content of the former NFPA 325.

If the atmosphere in a vapor space is in the flammable range, the hazard can be reduced or eliminated by:

— lowering the oxygen content by introducing an inert gas; or

— keeping the vapor space well above the upper flammability limit through the introduction of natural gas or the vapors of a volatile product.

Care must be taken in the use of these methods to avoid contamination of the product and prevent harmful exposure to personnel.

A.8.7 Electrostatically Active Fuels and Prostatic Agents

In some cases, accidents attributable to static electricity have occurred even where operations have been carried out for years in substantially the same manner without incident. In an attempt to account for these unusual occurrences, it has been postulated that in these instances the fuel was unusually electrostatically active because of the presence of unknown trace components that increased the charging tendency without significantly changing the fuel's conductivity [3]. API-sponsored research has eliminated most simple polar compounds and common fuel additives as having pro-static effects; however, it has been found that petroleum-derived sodium sulfonates are electrostatically active in trace concentrations. Water was found to be the most nearly ideal pro-static agent. The magnitude of its effect varied between fuels, leading to the conclusion that interaction with some undetermined constituent of the fuel provides the observed effect.

Present knowledge is inadequate to permit prediction of so-called "hot" fuels. Conventional fuel inspections give no indication of this potential hazard. However, hot fuels do occur occasionally, and the possibility must not be overlooked when loading precautions are considered or accidents are investigated.

A.8.8 Precautions Against Electrostatic Charging of Personnel

In a dry atmosphere, such as in a heated building in the winter, electrostatic charging of personnel can become noticeable. The human body is a good conductor for static electricity. Because of its significant capacitance to ground, the body can store an amount of energy in excess of the ignition energy for common hydrocarbons. Body potential of 10kV to 50 kV can be attained by individuals involved in industrial operations. Static discharges from clothing are very unlikely to ignite ordinary hydrocarbon gases in the air. Sparks from the body to ground may have sufficient energy for ignition, however, because the body is a fairly good conductor and may retain a charge.

Physical separation of dissimilar materials is always involved in the generation of a high body voltage. Some typical examples are:

— removal of an outer garment (charge separation between the garment and the remaining clothing and body);

— walking on a nonconductive surface (charge separation between the nonconductive surface and the soles of the shoes, which results in charging the body);

— cleaning an object by rubbing; contact with another charged object;

— being in the vicinity of another charged object.

Under “favorable” conditions, many fabrics can generate static electricity. This can occur when the fabrics are brought into contact with other materials and then separated, or when they are rubbed on various substances. Most synthetic fabrics (nylon, Orlon, Dacron, and rayon) are more active generators than are natural fabrics. However, clothing is not likely to generate high body voltage except by its removal. A few incidents have implicated synthetic outer garments and loose coveralls as potential direct or indirect source of ignition during operations where a flammable mixture was present due to static discharge (such as during re-fueling and tanker filling).

As a practical matter, static charging of personnel has not proven to be a significant safety problem in normal petroleum industry operations, probably because of the normal lack of actions such as those mentioned, coupled with normal precautions taken to prevent personnel being exposed to a flammable atmosphere.

The need for control of personnel charging usually arises in situations where workers are exposed to highly ignitable materials indoors, such as in hospital operating suites (with mixtures of oxygen and anesthetic gas) and in the manufacture of munitions. It can also arise in certain petroleum industry operations such as barrel filling of flammable liquids and in plastics handling operations. In these situations, prevention of personnel charging is achieved by continuous body grounding through the use of conductive footwear and conductive flooring.

These control measures are cited to illustrate that where a substantial risk from personnel static clothing exist, the use of antistatic clothing alone is not sufficient. Foremost, it is necessary to provide body grounding. Clothing treated with antistatic topical treatment (via washing or sprays) requires at least moderate humidity to be effective and it is difficult to maintain its anti-static properties. Clothing provided with antistatic properties by the addition of conductive fibers does not suffer from these drawbacks but can be more uncomfortable to wear.

As used here, grounding of personnel for electrostatic hazards does not mean a short circuit but a resistance on the order of 100,000 ohms from the body to ground. However, for protection from electric shock, resistance to ground should not be less than 10,000 ohms. Body grounding is the most basic and essential control measure. In addition, outer clothing can be chemically treated to make it somewhat conductive, and the use of synthetic fibers can be restricted. However, such controls are apt to be ineffective in a very dry atmosphere, so humidity control is usually employed as well. A possible alternative to conductive clothing that does not depend on humidity is the use of a cloth containing a small percentage of metal fibers in the thread. The purpose of the metal fibers is not to provide conduction but to promote safe corona discharge at a relatively low voltage.

Annex B
(informative)

Measurement and Detection of Static Electricity

B.1 Measurement General

Measurements useful in petroleum industry studies of static electricity include the determination of pertinent properties of the fluids involved and the magnitude of static effects resulting from specific operations.

Measurements of practical significance are difficult to make and interpret in relation to operating hazards. Considerable care must be exercised in selecting suitable methods of measurement and in interpreting results correctly. Instruments and information useful in static electrification studies are described in this annex.

B.2 Electrometer

An electrometer is frequently used for laboratory and field investigations of static electricity. This instrument is a specialized voltmeter that has very high input resistance and hence draws very little current. Equally important, it has a very low bias current (a self-generated current at the input). Solid-state electrometers employ either field-effect transistors or a varactor bridge in the input stage. Some electrometers are battery operated for portability. An electrometer can be used to measure very low currents or charges if it is provided with suitable resistors or capacitors.

B.3 Electrostatic Voltmeter

An electrostatic voltmeter operates on the principle of electrostatic attraction between metal plates when a potential is applied between the plates. The plates are similar to those used in variable radio capacitors. One plate has a pointer and is movable and its rotation is opposed by a spring. Moderately expensive, not too rugged, and fairly sensitive, this kind of meter is suitable for applications in which polarity indications are not important and continuous readings are desired. Its principal advantages are a nearly infinite input resistance and negligible bias current.

B.4 Electrostatic Field Meter

An electrostatic field meter, also called a field mill or generating field meter, measures electrical field strength. It contains a metal electrode exposed to the field to be measured. In front of the electrode is a rotating shutter that serves to chop the field, creating a periodically varying charge in the electrode. This alternating charge is electronically amplified and the output is fed to an indicating meter. The electrostatic field meter indicates the field strength (in volts per meter) at the electrode and shutter. Interpretation of this reading depends on the geometry of the environment in which the meter is located.

B.5 Charge Density Meter

The charge density meter, a variation of the electrostatic field meter, is designed to operate immersed in a charged nonconducting liquid. The device is used in a pipe or a constant-geometry outer shield. Under such conditions, the signals can be converted to the charge density in the liquid. Measurement of the charge density after the flow has been stopped provides a measurement of charge relaxation under actual conditions in the system at the location of the meter.

B.6 Conductivity, Temperature Effects, and Reproducibility

B.6.1 Conductivity

The conductivity of a fuel can be measured with an electrometer, a battery and a conductivity cell. Procedures for conductivity measurement are described in ASTM D4308 and ASTM D2624 and referenced in Section 2. The conductivity depends on the number of charge carriers in the fuel. The test procedure is designed to disturb the charge carriers as little as possible. Electrostatic charging of a fuel may increase or decrease the number of charge carriers and alter its conductivity.

B.6.2 Temperature Effect on Conductivity

Conductivity decreases with decreasing temperature and is inconsistent for varied fuels. Results from two reported data sets are shown in Table B-1. General observations are included in the table.

Table B.1—Effect of Temperature on Hydrocarbon Conductivity

Temperature		Conductivity in pS/m								
		Reference 1	Reference 2 Reporting on 8 Fuels							
Celsius	Fahrenheit		1	2	3	4	5	6	7	8
–20 °C	–4 °F	12	10	10	8	23	14	20	0	60
0 °C	32 °F	27	27	93	23	60	42	65	53	125
20 °C	68 °F	47	78	150	68	120	97	108	105	160++

General observations:

— Conductivity decreases substantially as temperature decreases.

— For the fuels reported the Modal Conductivity at freezing (0 °C) is about half of laboratory temperature (if 68 °C) and falls substantially and inconsistently when measured at –20 °C.

— Temperature response results range widely among different fuels.

— Temperature response may be affected by fuel composition (and perhaps additive treatment).

One conclusion could be that since conductivity varies inconsistently with temperature the conductivity of liquids needs to be established for the time and temperature of product transfer to properly evaluate the hazards.

When establishing precautionary handling procedures to protect against static electricity ignitions the temperature variance should be viewed with consideration of test reproducibility as discussed in the next section.

B.6.3 Conductivity Measurement Reproducibility

Information from ASTM standardized conductivity test standards shows that at low conductivity the reproducibility of the conductivity measurement is not good, with differences of up to 100 % between two successive measurements of the same liquid.

The two tests methods available have stated conductivity measurement reproducibility of:

— ASTM 2624 1 pS/m at 1 pS/m and 3 pS/m at 15 pS/m

— ASTM 4308 0.3 pS/m at 1 pS/m and 1.5 pS/m at 15pS/m

These measurement reproducibility values are determined under the best conditions including accurate temperature measurement, clean test equipment and experienced laboratory personnel. Reproducibility under field conditions is expected to be worse.

In addition to reproducibility, using a single measurement to represent the entire contents of a supply tank requires an assumption that the supply tank is well mixed and that there is no temperature or composition stratification. These conditions do not exist in the real world; therefore, it is essential that all static precautions be considered when below 50 pS/m.

B.7 Charging Tendency

Fuels vary in the degree to which they may be charged by passage through a Micropore filter. Coordinating Research Council Report 478 describes an apparatus that measures the fuel-charging characteristic by passing the fuel through a small filter and measuring the current. Because the current is highly dependent on the filter as well as the fuel, the measurements must be referenced to the filter employed.

B.8 Miscellaneous

When static discharge occurs, sparks can be detected by direct observation, radio receivers, or the ignition of an existing flammable mixture. However, quantitative appraisal of spark intensity is difficult. The gold-leaf electroscope is the classical device for detection of static charges. Although it is simple, portable, and sensitive, its use is limited primarily to classroom demonstrations. Neon lamp devices are less sensitive and are used only for demonstrations or as rough indicators of charge.

Annex C
(informative)

Direct Strike Lightning Protection Systems

C.1 General

There are three general types of commercially available lightning protection systems, as follows:

1) conventional air terminal lightning protection systems;

2) charge transfer, ionizing, or streamer delaying lightning protection systems;

3) early streamer emitting air terminal lightning protection systems.

Each of these system types is comprised of two basic subsystems, as follows.

a) The devices that are installed on top of or above the structure or area to be protected. These devices may include single point air terminals, multipoint air terminals, shield wires, masts, ionizers, etc. Systems using these devices offer protection from direct strikes to objects and structures that fall within a protected zone adjacent to and beneath the highest point of the devices.

b) A grounding electrode system designed to provide a sufficiently low resistance connection to earth. The lightning protection devices listed above (in paragraph a) must be bonded to the grounding system using conductors adequately sized for lightning currents.

The grounding subsystems for all three types of lightning protection systems are essentially identical. However, there are differences in the design and installation of the lightning protection devices (listed in paragraph a), as described below.

C.2 Conventional Air Terminal Lightning Protection Systems

A conventional air terminal lightning protection system consists of installing a suitable number of air terminals (also called lightning rods), conducting masts or overhead shield wires above the structures or areas to be protected. These devices are then bonded to the grounding system. The air terminals, masts or shield wires are designed to collect incoming lightning strikes by generating upward streamers. Installation requirements and specific information about the protected zone can be found in NFPA 780. Conventional air terminal lightning protection systems do not protect against indirect lightning currents or induced voltages. These effects are addressed by proper bonding and the application of surge protection devices.

C.3 Charge Transfer, Ionizing or Streamer Delaying Lightning Protection Systems

A charge transfer, ionizing, or streamer delaying lightning protection system consists of installing a suitable number of ionizers or ionizing air terminals above the structures or areas to be protected. These devices are then bonded to the grounding system. The ionizers and ionizing air terminals are designed to avoid the termination of incoming lightning strikes by suppressing or delaying the formation of upward streamers. Installation requirements and specific information about the protected zone is available from the systems' manufacturers. Charge transfer, ionizing, or streamer delaying systems may have some benefit in reducing indirect lightning currents or induced voltages. However, proper bonding and surge protection devices should still be provided.

C.4 Early Streamer Emission Air Terminal Lightning Protection System

An early streamer emitting (ESE) air terminal lightning protection system consists of a suitable number of ESE air terminals above the structures or areas to be protected. These devices are then bonded to the grounding system. ESE air terminals are designed to generate upward streamers that launch sooner than conventional lightning rods, thus providing a more attractive point of termination. Installation requirements and specific information about the protected zone is available from the systems' manufacturers. Early streamer emitting air terminal lightning protection systems do not protect against indirect lightning currents or induced voltages. These effects are addressed by proper bonding and the application of surge protection devices.

Annex D
(informative)

Units of Measurement

Values for measurements in this document are generally provided in both "Customary" and SI (metric) units. To avoid implying a greater level of precision than intended, the second cited value may be rounded off to a more appropriate number. For instance, linear flow rates in lines use "rounded off" values as operational equivalents. Where specific Code or test criteria are involved, an exact mathematical conversion is used. The unit "gallon" refers to U.S. gallons.

Table D.1—Conventional (English) to Metric (SI) Units of Measure

Customary Unit	Metric Unit	Conversion Factor
Fluid Volume		
U.S. gallon, USG	liter, l cubic decimeter, d m^3 (e.g. 1 liter) cubic meters, m^3	1 gal = 3.785 l 1 gal = 3.785 d m^3 1 m^3 = 264.2 gal
barrel (42 USG)	liter	1 barrel = 159 liters
Weight		
Flow Rate		
gal/min.	cubic m/hour l/min. = lpm	1000 gpm = 227 m^3/hr 1000 gpm = 3785 lpm
feet per second = ft/s	meters per second = m/s	(Rounded to: 1 m/s = 3 ft/s)
Pressure		
pounds per square inch, psi	mm Hg	1 psi = 51.7 mm Hg
pounds per square inch, psi	pascal, Pa	1 psi = 6895 Pa
pounds per square inch, psi	bar	1 psi = 0.06895 bar
	bar	1 bar = 10^5 Pa
pounds per square inch, psi	kilopascal, kPa	1 psi = 6.895 kPa
Length		
foot, ft	meter, m	1 ft = 0.3048 m
inch, in.	meter, m	39.37 in = 1 m
Area		
square feet, ft^2	square meters, m^2	1 ft^2 = 0.0929 m^2 1 m^2 = 10.76 ft^2
Temperature		
degrees Fahrenheit, °F	degrees Celsius, °C (e.g. centigrade)	(°F –32)/1.8 = °C
Heat		
BTU/hr	watts, W	1 BTU/hr = 0.293 W
BTU/hr/ft^2	kW/m^2	1 BTU/hr/ft^2 = 3.154 W/m^2 1.00 kW/m^2 = 317 BTU/hr/ft^2

Bibliography

The following bibliography is not all-inclusive but will provide guidance to the reader and will provide supporting evidence for the restrictions given in the text. It includes potentially useful references which are not called out specifically in the body of the standard.

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