

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

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

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

OCIMF⁶, *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 $1 \text{ pS/m} = 1 \times 10^{-12} \text{ siemens per meter} = 1 \times 10^{-12} \text{ ohm}^{-1} \text{ m}^{-1}$. (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 Triboelectric (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 Triboelectric 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 induced 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.

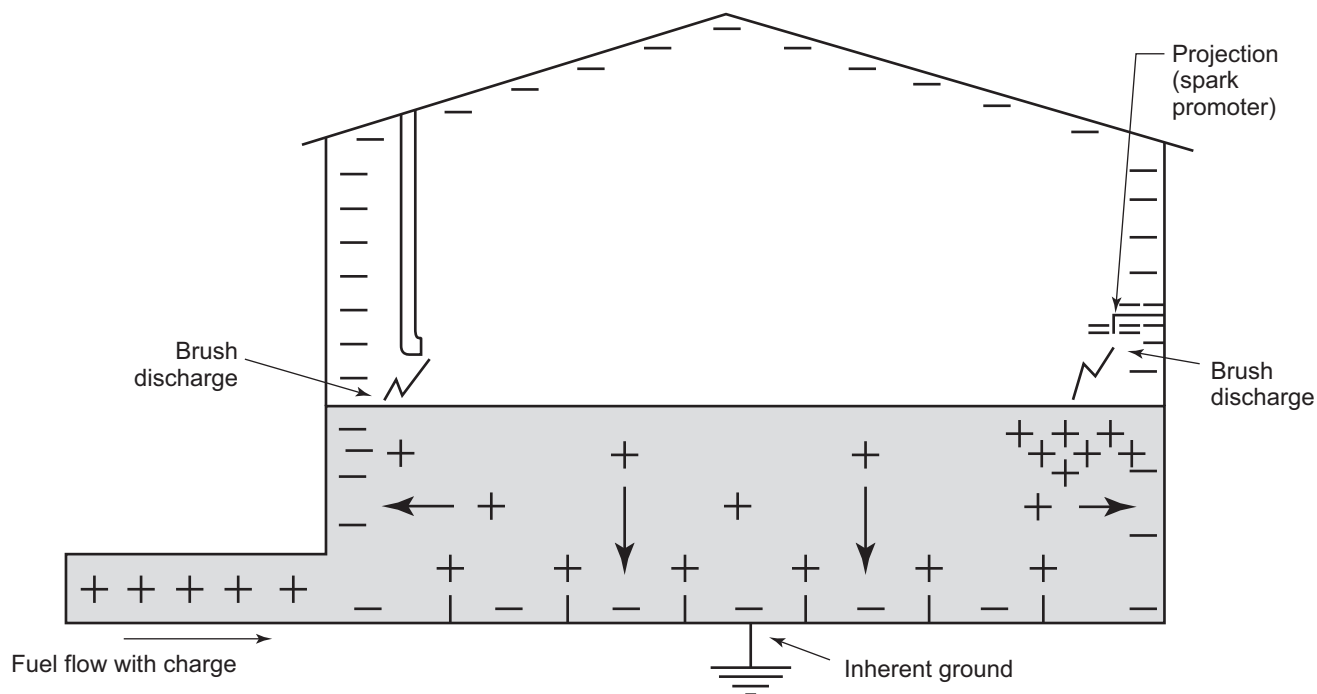


Figure 1—Fixed Spark Promoter

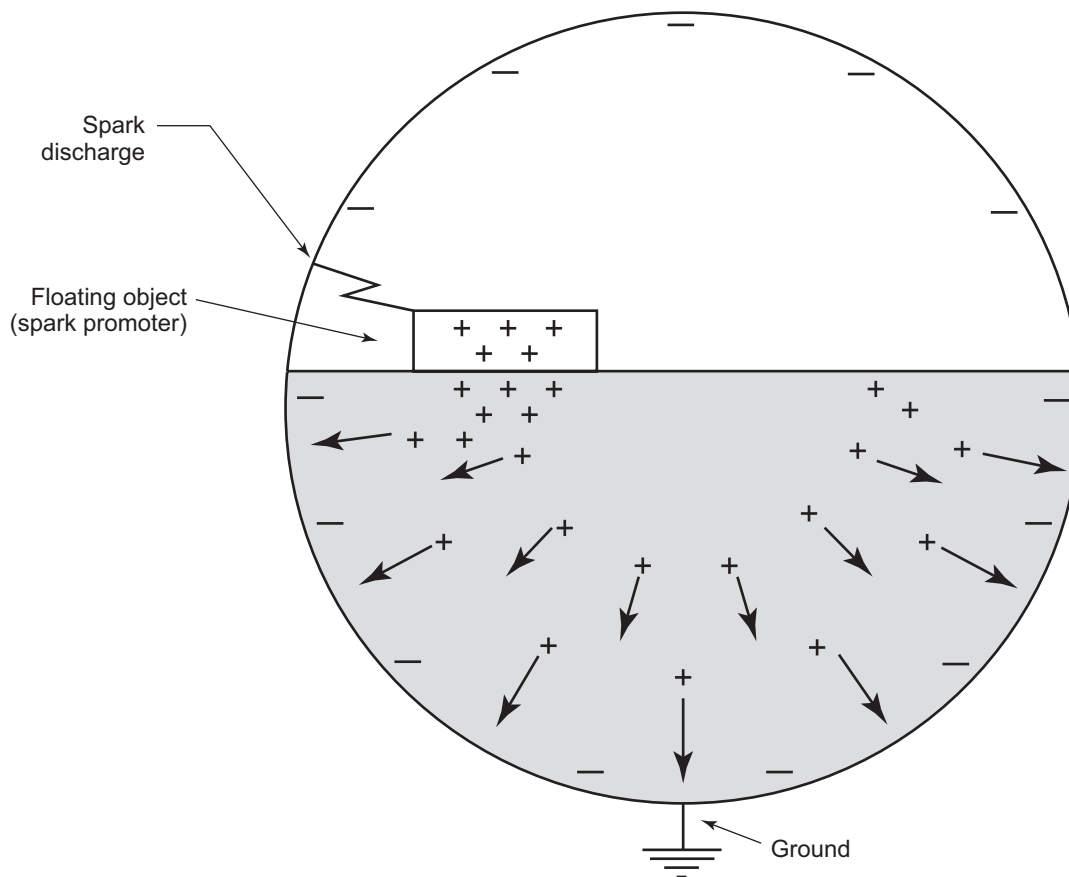


Figure 2—Floating Spark Promoter

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) 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.

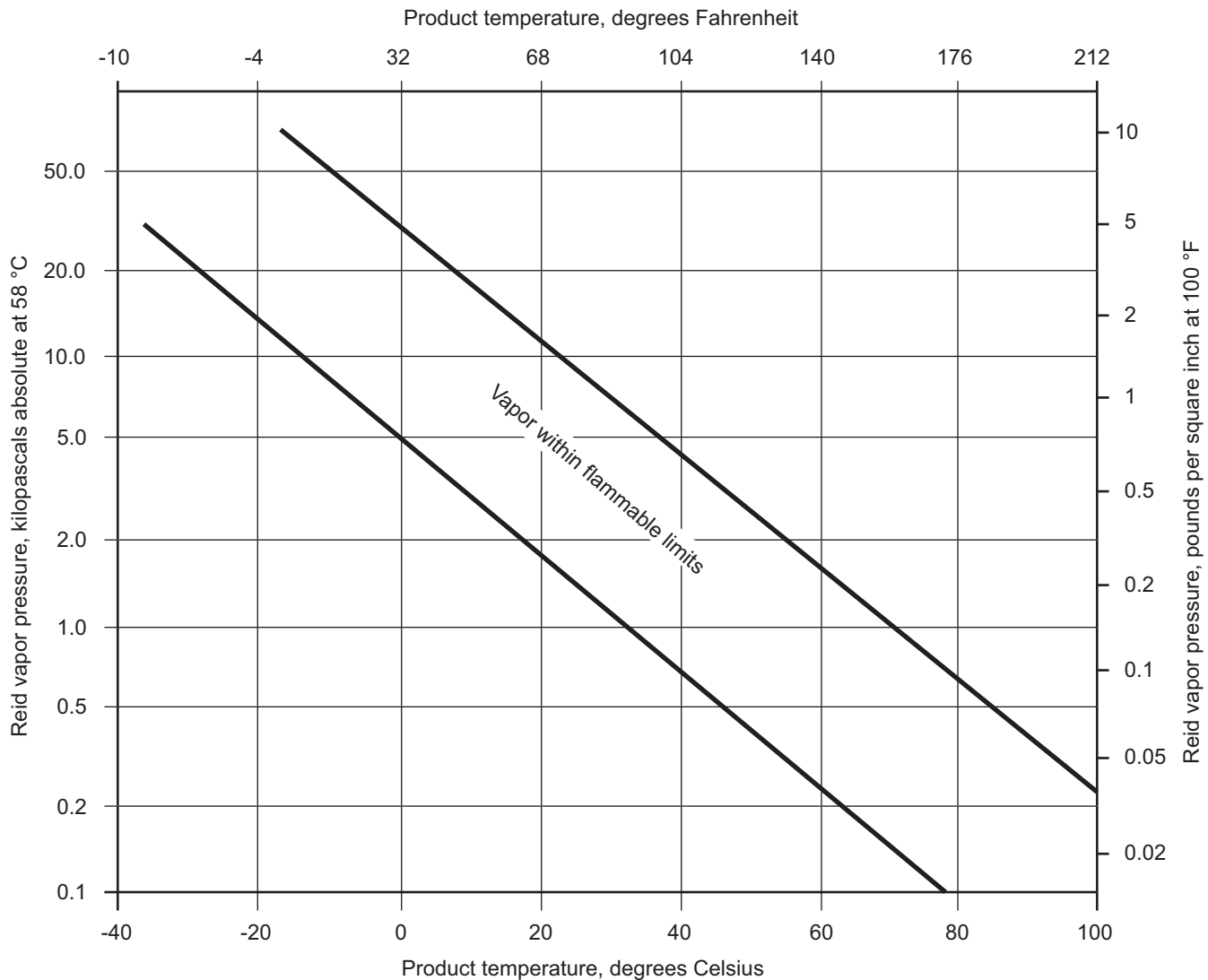
Figure 3, which shows the approximate correlation of Reid vapor pressure and product temperature to the flammable range (at equilibrium conditions), may be useful in estimating the temperature range within which a flammable vapor-air mixture is likely to exist.

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, 9}	> 100 sec ^{b, 9}	> 100 sec ^{f, 9}
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).

⁹ 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.

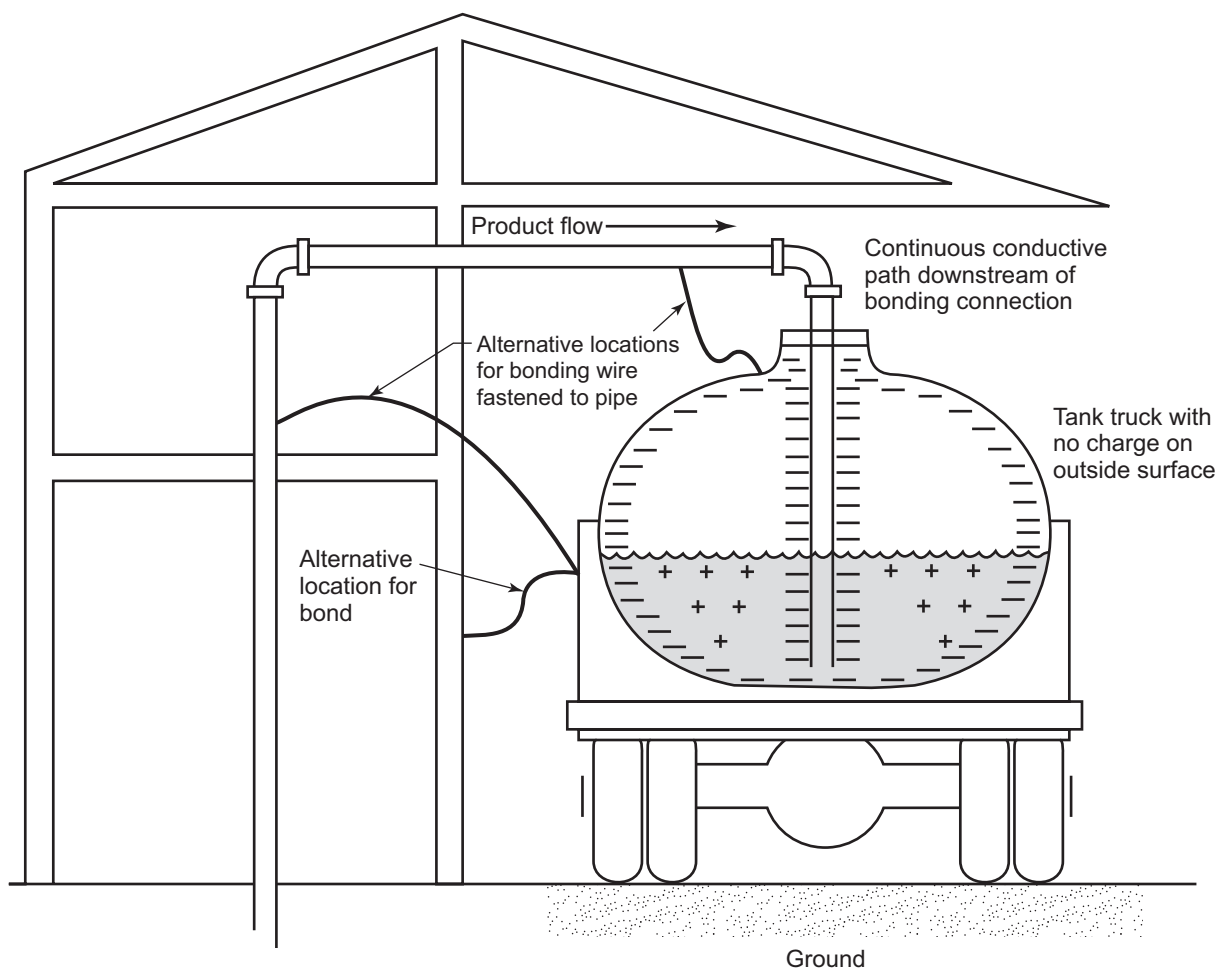


Figure 4—Tank Truck Bonding for Top Loading

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,

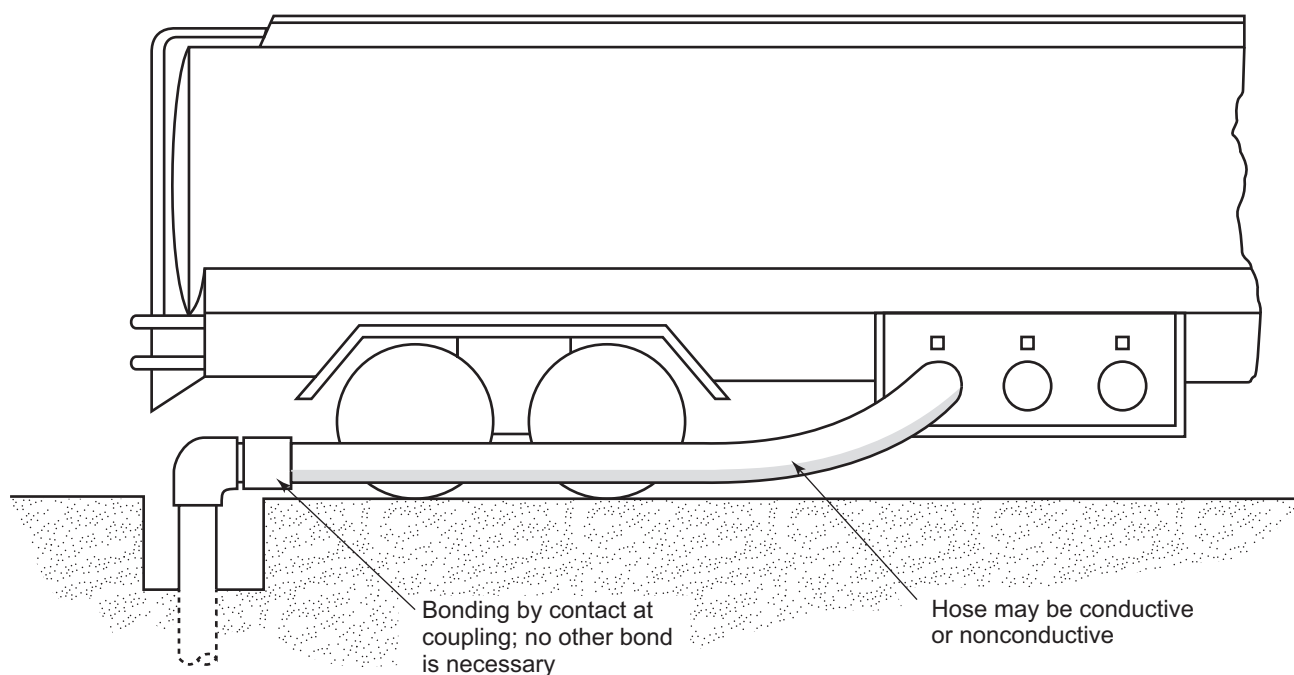


Figure 5—Loading and Unloading of Tank Trucks Through Closed Connections

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.)

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

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 m²/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 m²/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 0.38m²/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).